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Proceedings of

THE AFWAL/ML WORKSHOP ON NONDESTRUCTIVE EVALUATION OF AIRCRAFT CORROSION

REQUIREMENTS AND OPPORTUNITIES FOR RESEARCH AND DEVELOPMENT

24-25 May 1983
Holiday Inn-South
Dayton, Ohio

Organized and Conducted by

THE MATERIALS LABORATORY
NONDESTRUCTIVE EVALUATION BRANCH
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
WRIGHT-PATTERSON AFB, OHIO 45433

In Cooperation with

AIR FORCE LOGISTICS COMMAND
AIR FORCE COORDINATING OFFICE FOR LOGISTICS RESEARCH

Joint Military Service Participation

USAF – ARMY – NAVY – CANADIAN

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PROCEEDINGS OF
THE AFWAL/ML WORKSHOP ON NONDESTRUCTIVE EVALUATION OF AIRCRAFT CORROSION - Requirements and Opportunities for Research and Development

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Dr Joseph A. Moyzis, Chairman

THE MATERIALS LABORATORY
NONDESTRUCTIVE EVALUATION BRANCH
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
WRIGHT-PATTERSON AFB, OHIO 45433

WL/MLBC, TOBEY M. CORDELL
COMPOSITES GROUP, MATERIALS DIRECTORATE
WRIGHT-PATTERSON AFB, OH 45433-6533

WL-TR-92-4095

In cooperation with Air Force Logistics Command, Air Force Coordinating Office for Logistics Research.

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The purpose of this workshop was to develop recommendations for R&D NDE programs dealing with the detection of corrosion in aircraft structures and components based upon the identification of common generic corrosion problems in such structures and components. The following presentations were made: Air Force Corrosion Program NDE Requirements, Proposed Application of Nondestructive Evaluation to U.S. Army Aircraft Corrosion Problems, Naval Aviation Detection of Corrosion by NDE Procedures, Airline Corrosion/NDI Requirements, and Aircraft Corrosion and Detection Methods.

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PROCEEDINGS OF THE CORROSION NDE WORKSHOP

Dr Joseph A. Moyzis, Chairman

Ms Nancy M. Norton, Co-Chairman, Editor

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INTRODUCTION

Corrosion of equipment and material is a continuing problem for the nation, and certainly for the Armed Forces in their continuing struggle to keep military systems in full combat readiness. A recent study by the National Bureau of Standards, "Economic Effects of Metallic Corrosion in the United States", estimated that corrosion costs the U.S. economy over $70 billion per year. The corresponding figure for the Armed Forces is certainly in the billions.

The major concerns associated with corrosion are prediction, prevention, detection, and repair. The detection of corrosion in real structures is complicated by the myriad of geometric configurations encountered in these structures as well as by the fact that a significant fraction of corrosion is not immediately accessible to the inspector or to the commonly used inspection techniques.

Thus, much of the task of corrosion detection consists of matching specific inspection techniques to specific structure geometries. This ad hoc procedure is extremely difficult to use as the basis for meaningful R&D programs for the development of improved corrosion detection methods. Moreover, again because of the large number of individual inspection situations encountered, it is difficult to justify the expense of adequately evaluating the corrosion detection and characterization capabilities of any one inspection procedure.

If meaningful R&D is to be done in the detection of corrosion, that is, R&D which will lead to solutions of a significant sub-set of the corrosion detection problems encountered in the real world, it will be necessary to identify generic corrosion geometries against which more widely applicable inspection procedures can be developed and evaluated. To assist in the identification of generic corrosion geometries, the Materials Laboratory of the Air Force Wright Aeronautical Laboratories (AFWAL/ML) organized and conducted the Workshop on Nondestructive Evaluation (NDE) of Aircraft Corrosion on 24-25 May 1983 in Dayton, Ohio.

The purpose of this Workshop was to develop recommendations for R&D NDE programs dealing with the detection of corrosion in aircraft structures and components based upon the identification of common generic corrosion problems in such structures and components. The need for such programs has been identified by the Joint (USAF, USA, USN) Logistics Commanders in their 30 November 1979 charter establishing a panel on "Corrosion Prevention and Control".

To achieve the optimum results, the Workshop was organized as follows:

1. Draw together key corrosion and NDE experts representing a cross section of industrial and government experience in these areas.

2. Limit Workshop attendees to approximately 60 to ensure that a discussion mode would exist.

3. Present to the Workshop participants, through a series of short topical reviews by selected industry and government personnel, an overview of the many types of corrosion problems encountered in practice.

4. Identify, through several smaller discussion group sessions, the most representative corrosion problem areas to serve as baselines and the potential corrosion detection R&D program areas to pursue.

This document summarizes the presentations given to the Workshop attendees and the conclusions generated by the three discussion groups.

AFWAL/ML is indebted to each attendee - speakers, session moderators, and discussants alike - for their active participation and contributions to the objectives of the Workshop. AFWAL/ML also appreciates the administrative assistance of Universal Technology Corporation, Dayton, Ohio in organizing and conducting the Workshop. The assistance of Ms Sue Sobieski and Mrs Tami Rohrer, AFWAL/MLLP, in providing secretarial support for both the meeting and the proceedings is gratefully acknowledged.

FINAL AGENDA

Corrosion NDE Workshop
24-25 May 1983
HOLIDAY INN - SOUTH
Dayton, Ohio

Tuesday, 24 May

0715-0800	Registration	
0800	Announcements, Introduction by Workshop Chairman	Dr Joseph A. Moyzis AFWAL/ML-NDE Branch
0815	Keynote Address	Brig Gen Thomas A. LaPlante, HQ AFLC, Asst. DSC/Logistics Operations
0830	Workshop Overview	Dr Joseph A. Moyzis
0845-1135	Corrosion Detection as Practiced: Major requirements, current practices & limitations, and technology needs	
	0845 US Air Force Requirements	Lt Col Jesse R. Teal, Jr. AFLC/WR-ALC, Robins AFB, AF Corrosion Program Mgr.
	0915 US Army Requirements	Mr Windel Baker Army Aviation R&D Command-NDI, St. Louis
0945	COFFEE/TEA BREAK	
	1005 US Navy Requirements (NAVAIR, NADC)	Mr E. C. (Ed) Holland Naval Air Sys Command, NDI Applications Mgr., Washington
	1035 NDI, Airline Requirements	Mr Peter Opar US Air, Director of Quality Assurance, Pittsburgh
	1105 Aircraft Manufacturer's Prospective	Mr Donald J. Hagemaier NDE Unit Chief in Mat'ls & Process Eng., Douglas Aircraft Co., Long Beach
1135	Workshop Strategy & Goals	Dr Joseph A. Moyzis
1150-1250	BUFFET LUNCHEON	

1250-1630	Concurrent Workshop Sessions:	
	Problem Selection - Accessible Airframe Corrosion: Generic corrosion situations in exterior or accessible airframe locations for which no inexpensive, efficient NDE methods exists.	Chairman: Mr Grover Hardy, AFWAL/ML Systems Support Div., Materials Integrity Branch Asst: Mr James Holloway
	Problem Selection - Inaccessible Airframe Corrosion: Generic corrosion situations in hidden inaccessible locations for which no satisfactory NDE methods exists.	Chairman: Lt Col Garth Cooke, HQ AFLC, Logistics Operations, Service Engineering Div. Asst: Mr Fred Meyer
	Inspection/Detection Methodology - General Constraints: Long term vs. near term (how futuristic?). Applicability for corrosion detection (how feasible?). Impact of signal processing/micro-processors.	Chairman: Mr Joseph Koos, AF Acquisition Logistics Div., Aeromechanical Engineering Asst: Mr Stephen Moore
1430-1445	INFORMAL REFRESHMENT BREAK	
1630	ADJOURN	
1630-1700	Workshop Session Leaders/Assistants Meeting Only	

Wednesday, 25 May

0730-0800	Informal	
0800-0930	Concurrent Workshop Sessions (continued)	
0930	COFFEE/TEA BREAK	
1015	Plenary Session - Workshop Session Leaders present reports	
1155-1255	LUNCH - OPEN	
1255	Open Discussion & Consensus on action items	
1415	Closing Remarks	Dr Joseph A. Moyzis
1430	ADJOURN PLENARY SESSION	
1430	REFRESHMENT BREAK	
1445-1600	Government Only Session	

CORROSION NDE WORKSHOP
24-25 May 1983
Holiday Inn South

ATTENDENCE LIST

Mr. Robert J. Andrews
Univ. of Dayton Research Institute
300 College Park Ave., M/S KL102
Dayton, OH 45469

Mr. Robert Bailey
WR-ALC/MMEMM
Robins AFB, GA 31098

Mr. Windel M. Baker
US Army Aviation R&D Comd.
DRDAV-QE
4300 Goodfellow Blvd.
St. Louis, MO 63120

Mr. John R. Barton
Vice Pres.-Instrumentation Res. Div.
Southwest Research Institute
6220 Culebra Road
San Antonio, TX 78284

Mr. William E. Berner
Materials Engineer
ASD/TAEF
WPAFB, OH 45433

Mr. Bernard Boisvert
Universal Technology Corporation
1616 Mardon Drive
Dayton, OH 45432

Mr. Phillip C. Borja
Naval Air Rework Facility
Code 31116
North Island
San Diego, CA 92135

Mr. Gerald T. Carr
Metal Process Inspector
Corpus Christi Army Depot
M/S 27
Corpus Christi, TX 78419

TSgt. Maurice Carter
AFWAL/MLSA
WPAFB, OH 45433

Mr. Richard Chance
Grumman Aerospace Corp.
M/S A01-10
Bethpage, NY 11714

Mr. Ronald Clay
OO-ALC/MMETP
Hill AFB, UT 84056

Mr. Bennie Cohen
AFWAL/MLSA
WPAFB, OH 45433

Lt. Col. Garth Cooke
AFLC/LOEA
WPAFB, OH 45433

Dr. Robert Crane
AFWAL/MLLP
WPAFB, OH 45433

Mr. Bob Dahl
SM-ALC/MANCC
McClellan AFB, CA 95652

Mr. Pascal B. Daniels
Sikorsky Aircraft
Div. of United Technologies
North Main Street
Stratford, CT 06497

MSgt. Danny R. Daugherty
Corrosion Control Mgr.
TAC/LGMD
Langley AFB, VA 23665

Col. W. M. Egan
AFLC/LOE
WPAFB, OH 45433

Mr. Donald M. Forney, Jr.
AFWAL/MLLP
WPAFB, OH 45433

2nd Lt. Mark Forte
AFALD/PTEM
WPAFB, OH 45433

Ms. Sarah Garrett
General Dynamics Corp.
Fort Worth Division
PO Box 748, MZ 6618
Fort Worth, TX 76115

Mr. Roger Griswold
AFWAL/MLSA
WPAFB, OH 45433

Mr. Lee Gulley, Jr.
AFWAL/MLTM
WPAFB, OH 45433

Mr. Donald Hagemaier
McDonnell-Douglas Corp.
Dept. C1-253, M/S 35-14
3855 Lakewood Blvd.
Long Beach, CA 90846

Mr. Grover Hardy
AFWAL/MLSA
WPAFB, OH 45433

Lt. Col. John Hernandez
Chief, Policy Division
HQ. AFSC/SDXP
Andrews AFB, DC 20334

Mr. Edmund Holland
NAVAIRSYSCOM
Code AIR 4111/C3
Washington, DC 20360

Mr. James Holloway
AFWAL/MLLP
WPAFB, OH 45433

MSgt. David W. Hubbard
Subsys-Supp Equip SPO
ASD/AEGS
WPAFB, OH 45433

Dr. M. Khobaib
Scientist
AFWAL/MLLN
WPAFB, OH 45433

Mr. Henry Kleindienst
Chief of Matl's & Processes
Fairchild Republic Co.
Farmingdale L.I., NY 11735

Capt. Greg Knapik
ASD/AFXM
WPAFB, OH 45433

Mr. Joseph Koos, Jr.
AFALD/PTEM
WPAFB, OH 45433

Mr. Harley F. Latta
NDT Manager
ASD/ENFSS
WPAFB, OH 45433

Brig. Gen. Thomas A. LaPlante
Asst. DCS/Logistics Oper.
HQ. AFLC/LO
WPAFB, OH 45433

Mr. James D. Lawyer
Chemical Engineer
AFLC/MAXT
WPAFB, OH 45433

Mr. Milton V. Levy
Chief, Corrosion Res. Br.
Army Matl's & Mech. Res. Ctr.
Arsenal St., M/S DRXMR-MMS
Watertown, MA 02172

CMS John Lindsey
HQ.-MAC/LGMWB
Scott AFB, IL 62225

Mr. Agustin Lopez
SA-ALC/MMEI
Kelly AFB, TX 78241

Mr. Anthony Martinez
Mechanical Engineer
SA-ALC/MMETM
Kelly AFB, TX 78241

Mr. Terrance W. Mattson
Structures Engineer
Boeing Company
PO Box 3707, M/S 9H-81
Seattle, WA 98124

Mr. Fred H. Meyer
Matl's Eng.-Corrosion Spec.
AFWAL/MLSA
WPAFB, OH 45433

Mr. John F. Moore
Member, Tech Staff
Rockwell International/El Segundo
PO Box 98075, M/S GD08
Los Angeles, CA 90009

Mr. Stephen E. Moore
Supv. Phys. Scientist
SM-ALC/MAQCA
McClellan AFB, CA 95652

Dr. Joseph A. Moyzis, Jr.
Technical Area Mgr.
AFWAL/MLLP
WPAFB, OH 45433

Ms. Nancy Norton
AFWAL/MLLP
WPAFB, OH 45433

Mr. Peter Opar
USAir
Greater Pittsburgh Int'l. Airport
Pittsburgh, PA 15231

Mr. James M. Pittman
Mgr., Quality Engrg.
Fairchild Republic Co.
Conklin St., M/S 17G24
Farmingdale, NY 11735

Mr. Robert C. Placious
Physicist
National Bureau of Standards
216C-Bldg 245
Washington, DC 20234

Cmdr. A.H. Robbins
NAVAIRSYSCOM
Code 4111C
Washington, DC 20360

Mr. Ward D. Rummel
Program Manager
Martin-Marietta Corp.
Denver, CO 80201

Dr. Vincent J. Russo
Acting Dir. Chief-
Metals & Ceramic Div.
AFWAL/MLL
WPAFB, OH 45433

Mr. Daniel M. Sheets
Aero Eng.
AFCOLR/ES
WPAFB, OH 45433

Mr. Ira Smart
HQ. DARCOM/DRCQ A-E
5001 Eisenhower Ave.
Alexandria, VA 22333

Mr. William Sproat
Lockheed-Georgia Co.
D/72-54, Zone 415
86 S. Cobb Drive
Marietta, GA 30063

Mr. Michael Stellabotte
NAVAIRDEVCTR
Code 6063
Warminster, PA 18974

Mr. Gary Stevenson
AFWAL/MLSA
WPAFB, OH 45433

Mr. Emory E. Stewart
Aerospace Eng.
AFLC/LOEA
WPAFB, OH 45433

Mr. William R. Sturrock
Defence Scientist
Defense Res. Estab., Pacific
FMO/CFB ESQUIMALT
Victoria B.C., Canada VOS-1BO

Lt. Col. Jesse R. Teal, Jr.
WR-ALC/MMEM
Robins AFB, GA 31098

Mr. John C. Toelaer
Q.A. Spec.
TSARCOM/DRCPM-BH-QP
4300 Goodfellow Blvd.
St. Louis, MO 63120

KEYNOTE ADDRESS TO THE WORKING GROUP ON CORROSION NDI

by Brig Gen Thomas A. LaPlante
HQ AFLC
Assistant Deputy Chief of Staff/Logistics Operations

Good morning, I am especially pleased to be addressing this group today because you are examining a problem which is of great interest to my command. The Air Force Logistics Command performs all depot level work on USAF aircraft and inspection of those aircraft is a major part of our work. In conjunction with AFSC, we prepare the procedures and provide the equipment which all the users of Air Force aircraft must use for their inspections. Since one of the major structural problems we have to inspect for is corrosion, and since those inspections consume so much of our manpower the need for effective, efficient inspection systems becomes obvious.

Not only is the need obvious to us in AFLC, it is apparent that the need is also recognized by both the Army and the Navy. In October 1980, the Joint Logistics Commanders established a Joint Panel on Corrosion Prevention and Control. One of the specific tasks levied on that panel was to provide special emphasis on development of quick, portable NDI techniques and hardware for use by maintenance personnel. The corrosion mafia aren't the only ones who have recognized this need. The Joint Technical Coordinating Group on NDI has also established the development of an effective corrosion inspection technique as one of their high priority tasks.

Before I proceed to the part of my address which encourages you to work hard and provide the kind of results we need to get this program off the ground, let me cite just a few specific examples of the magnitude of the problem we face and the kinds of manhour resources which are consumed in corrosion inspection using the techniques available to us today. The maintenance technical orders for the C-5 direct a visual inspection of the aircraft exterior for corrosion. Now everyone knows that the C-5 exterior is covered with paint so how do you inspect this monster for corrosion? The answer is that you inspect the paint surface for evidence that corrosion is taking place under the paint. Experience tells us that corrosion of this type is most likely to occur around or near fasteners, so that limits the scope of the inspection a little. However, do you have any idea how many fasteners there are on the C-5? (over 1 million!) Furthermore, the corrosion we're looking for doesn't jump up and shout "Here I am." We have to look closely at each of the fasteners, and each time there is some question as to whether there might be corrosion present, out comes the trusty ten power glass. Now we have a field of view of about one-fourth square inch. Inspecting the fasteners on the C-5 with a ten power glass is ridiculous, but that's what we're reduced to because no one has yet developed a better way. At one time we thought we could get away with assuming corrosion was not a problem on aircraft surfaces if there were no external evidence such as lifting or blistering of the paint. Last year we stripped the paint from an A-7 aircraft which had spent its whole life in Tucson, Arizona. There was no external evidence of a corrosion problem under the paint, but we discovered that over 85% of the external surfaces were covered by corrosion. (Note: The aircraft was stripped as a result of a fleetwide mid-life program being conducted on the A-7's; the wide spread corrosion was the result of using zinc chromate primer during aircraft production.)

Many of our depot inspections for corrosion are performed using conventional NDI techniques such as x-ray, ultrasonics, and eddy current, but I submit that these are pretty inefficient ways to look for this problem. Most of our aircraft have been through depot maintenance a large number of times, and many have had corrosion problems corrected through the time honored (and correct) technique of "grind out and recoat." When we apply the conventional techniques of NDI, all we're really looking for is the presence or absence of sound metal. If we get a change from the expected signal response, we may be identifying an old repair rather than a corrosion problem. The extensive disassembly needed to find out which it is can be a damned expensive way to learn we repaired it right the last time.

I could go on and on with recitations of the kinds of problems we face because we don't have a good technique to find corrosion, but that's for other speakers to do today. I would, however, like to talk very briefly about two techniques which actually do detect corrosion. Early work on neutron radiography conducted in the mid-and-late seventies showed that technology to be very promising. An early test conducted by the Navy showed neutron radiography to be more effective than x-ray, ultrasonics, eddy current, and visual inspection combined. However, we don't seem to have made a whole lot of progress in that particular technology recently, and I would like you to address what can be done there. In addition, our depot at Sacramento has developed a pretty sophisticated capability to detect wet corrosion in aluminum honeycomb on the F-111. This use of acoustic emission technology has been in effect for more than five years, yet application is still pretty much limited to the F-111 use we started with. Perhaps this workshop should address ways to move that particular technology into support of other weapon systems.

That's enough from me, I'm not an expert in either corrosion or NDI. I can recognize and expound upon the problem, but you are the people who must help by coming up with solutions. I sincerely welcome you to Dayton, and hope that you have a very pleasant and productive conference. We need the type of guidance that only a group such as this can provide, and you may be assured that productive results from this meeting will translate into positive actions from the Air Force. Thank you and good luck!

AIR FORCE CORROSION PROGRAM
NDE REQUIREMENTS

by Lt Col Jesse R. Teal, Jr.
AF Corrosion Program Manager
Robins AFB GA

General Needs [Viewgraph 2]

- Better Corrosion Inspection (Nondestructive) Methods
  - Quantitative (How bad is the corrosion?)
  - Reliable
  - Reproducible
  - Rapid
  - Economical

  (The NDI must be forgiving of slight changes in coating, sealant, and sound metal.)
- Improved Corrosion Inspection Procedures
  - New design technology
  - New manufacturing Technology

Currently Available Methods of Inspection [Viewgraph 3]

- Methods are Available (Some of these methods require 1000 hours of disassembly, inspection and reassembly for areas which cannot be inspected in situ.)
- Specific Procedures Must be Developed (currently specific NDI procedures are developed for each identified corrosion detection problem.)
- Restrictions/Hindrances
  - Corrosion process is slow (except for stress corrosion cracking and corrosion fatigue cracking)
  - Corrosion damage hides from us (it varies within individual aircraft)
  - Significant damage must occur (Corrosion protection coatings/ sealants complicate the inspection process by absorbing or scattering the interrogating signals [ultrasonic, eddy current, X-ray, and N-ray] or by masking corrosion damage preventing visual, magnetic particle or penetrant inspections.)

Successful Corrosion Detection Methods [Viewgraph 4]

- Single Layer Corrosion (Ultrasonics can find expected thickness changes.)
- Tubular Corrosion (Typical radiographs are provided to inspectors for comparison, e.g. for the aileron tab assembly.)
- Honeycomb Structure (Ultrasonics finds disbonds; acoustic emission is used to detect water in honeycomb of the F-111 components; and eddy current and sonics have proved successful in inspecting the H-1 helicopter.)

  (Warner-Robins ALC and the Corrosion Office are investigating the ruggedization of a resistance probe for in situ detection of corrosion in inaccessible areas.)

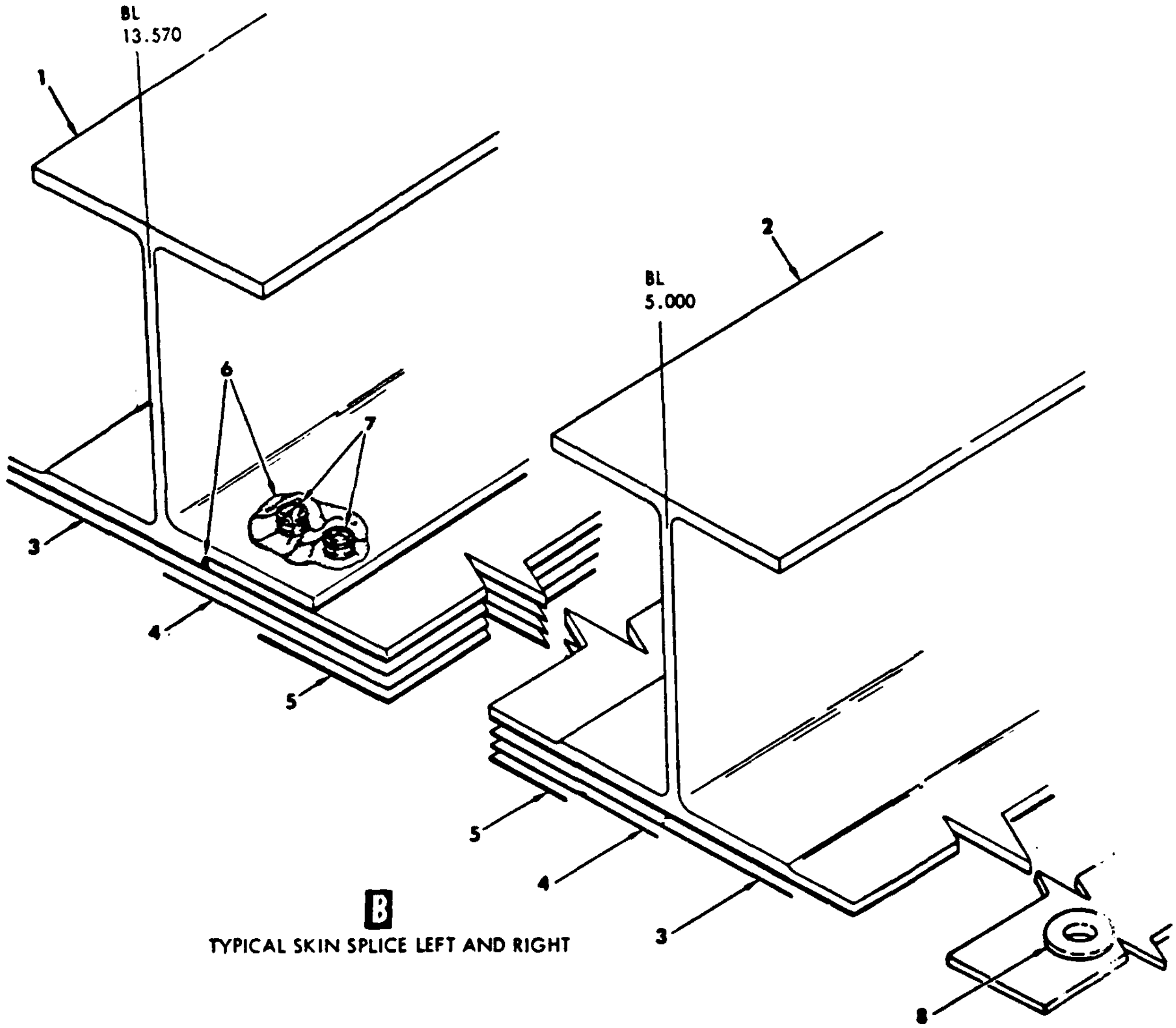
  (In the last fifteen years in the Air Force no single catastrophic accident can be attributed to corrosion damage except in cases where corrosion has led to further cracking of the material.)

Viewgraphs 5 and 7 are shown on the next two pages.

Viewgraph 6 [not included] showed x-rays of aileron control rods containing interior corrosion pits as an example to demonstrate detection of corrosion inside tubular components.

Challenges [Viewgraph 8]

- A-10 Corrosion Under Fuel Bladders
- Complex Geometry
- Severity of Corrosion Damage
- Coating System Condition
- Multi-Layer Construction
- Corrosion Under Paint



B

TYPICAL SKIN SPLICE LEFT AND RIGHT

C

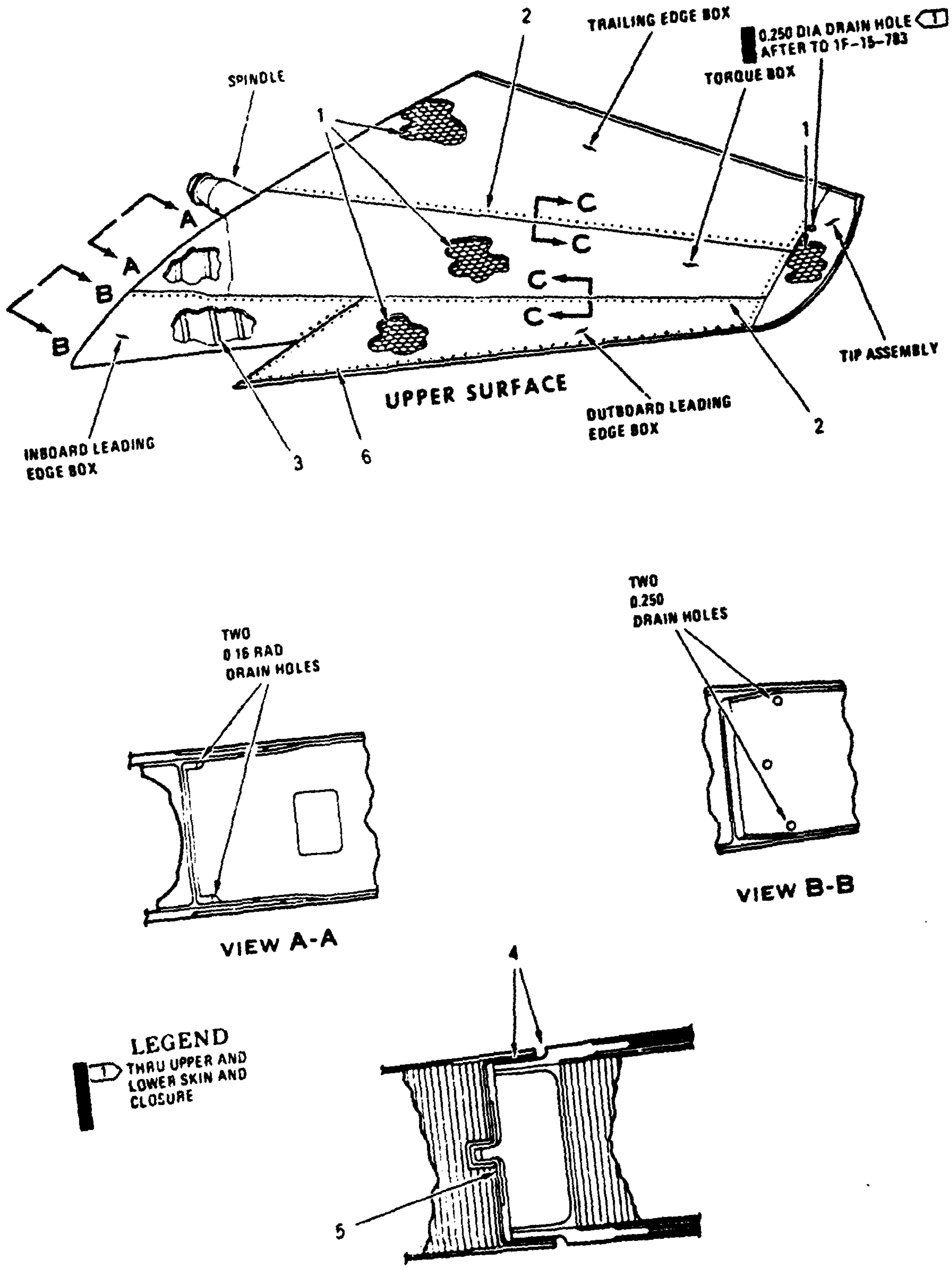
TYPICAL KEEL BEAM DRAIN HOLE INSTALLATION

1. RIGHT SKIN PANEL
2. CENTER SKIN PANEL
3. PRIMER COATING, INHIBITED ELASTOMERIC COATING 0.003 TO 0.005 (PR-1432-G).
4. INTERMEDIATE COATING, INHIBITED ELASTOMERIC COATING (PR-1436-G).
5. TWO COATS OF SPECIFICATION MIL-C-83286 POLYURETHANE ENAMEL (NO. 16473 GRAY)
6. INHIBITED SEALING COMPOUND (PR-1422-G B2)
7. FASTENERS
8. DRAIN HOLE WITH SLEEVE INSTALLED (TYPICAL 89 PLACES).

Corrosion Removal, Treatment, and Refinishing of the Keel Beam Exterior Skin Panels

VIEWGRAPH 5

F-15



Stabilator Corrosion Prone and Critical Items/Areas

VIEWGRAPH 7

Needs of the Corrosion Prevention Program by Priority [Viewgraph 9]

1. Detecting and determining extent of corrosion without disassembly.
2. Detection of corrosion between and beneath multiple layers of metals/materials.
3. Detection of corrosion under sealant.
4. Detection of corrosion beneath paint (before bubbling). Determination when coating system fails to perform its function of preventing corrosion.
5. Identification of suspected corrosion by scanning large areas.
6. R&D into what potential problems we face with composite and pabst structures.

PROPOSED APPLICATION OF NONDESTRUCTIVE EVALUATION
to
US ARMY AIRCRAFT CORROSION PROBLEMS

by Windel M. Baker
Army Aviation R&D Command

Introduction

My presentation today will show examples of corrosion on helicopters found during our recent field visits. Corrosion prone areas where the most difficulty occurs will be identified and corrective actions taken to eliminate or reduce corrosion will be addressed. Also covered are the areas where a good NDE method which could be used for field or depot inspections would be appropriate.

Photograph 1 - Main Rotor Mast Extension

This is the view downward from the mast of a helicopter. The mast is in the center of the helicopter and drives the rotor blades. There is a cover which will be shown on the next photograph. This cover does not seal properly and in forward flight in wet conditions the mast fills up with water. Looking down into the bottom of the hole you can see areas where water has been standing. Also, you can see corrosion on the top of the nut and other parts down in this hub.

Photograph 2 - Main Rotor Mast Extension Cover

The cover is the round piece under the plastic duct. You can see that the holes are spaced well apart. When the cover is tightened down, it buckles up so that water can get under the cover and can fill up inside the mast. This was shown in the previous picture.

Photograph 3 - Main Rotor Retention Nut

Down in the mast or shaft is this steel nut which is cadmium plated. This is the nut that holds the whole rotor head together. In rotor aircraft jargon, this is referred to as the "Jesus nut". If it fails in flight the aircraft is lost. The picture shows extensive corrosion. The Army has changed the material of this nut to prevent corrosion. Also, an improved cover for the mast is now being installed. Other improvements inside the hub have increased the water repelling integrity of the main rotor system to keep the water out and prevent corrosion.

Photograph 4 - Pitch Change Link

This view is of the pitch change link. The shiny ball is the spherical bearing. We are detecting some corrosion pitting in this area. The contractor has given us accept-reject parameters with respect to the depth of the pits. Right now measurement is difficult because the tolerances are tight and the depth of these pits cannot be determined by present field methods. Previously there was a boot that covered the entire bearing. Its purpose was to protect the bearing from the weather elements. However, we found it trapped and held the water that entered around the bearing. The boots have been removed and the bearings composition changed to prevent corrosion. There are other bearings on the aircraft that are similar to this and they also will require this inspection.

Photograph 5 - Main Landing Gear Strut (Functional)

This is the landing gear strut which is almost horizontal running from the wheel to the lower side of the aircraft.

Photograph 6 - Main Landing Gear Strut (Non-functional)

This is what happened to two aircraft. Failure was caused by pitting in one of the holes for the brake line. Stress corrosion cracking initiated from this pitting. Subsequent investigation of this failure necessitated a design change requiring shot peening, cadmium plating, and baked resin in the interior of these beams. Also, the corrosion prevention coating was properly applied inside the drag beam at the top but became progressively thinner further down until, at the bottom, the beam had no protective coating whatever. Because coating thickness is difficult to measure, there is a need for a viable NDE technique, usable in the field, which could be applied externally to detect the thickness of the internal coating. One possible fix is to put epoxy primer inside the tube and then fill the tube with foam. This will prevent water from entering the tube to initiate corrosion.

Photograph 7 - Main Rotor Blade

This is a cross section of a typical metal rotor blade looking from outboard to inboard. You will notice the skin at the bottom has peeled because of underlying corrosion. This is the result of poor field inspection. Field personnel are required to wipe down the blade every day and to look for corrosion. It is obvious that if it had been inspected according to the manual this would not be a problem. The Army is inspecting with NDE, ultrasonic and harmonic bond testing, but most of the time a coin tap or visual inspection can detect any areas of corrosion or delamination of the skin.

Photograph 8 - Aircraft Control Tubes

Control rods are potential trouble spots on most aircraft. The control rods are swaged at the ends. Water enters the control tubes causing internal corrosion. There is no apparent way to determine the existence or the extent of corrosion. An appropriate NDE method to determine the extent of corrosion in the area is needed. On older aircraft many control tubes must be rejected because the depth or amount of corrosion is unknown. In many instances the tubes were not properly cleaned before application of the zinc chromate primer making the zinc chromate primer ineffective. An epoxy primer is now used inside the tube instead of the zinc chromate primer.

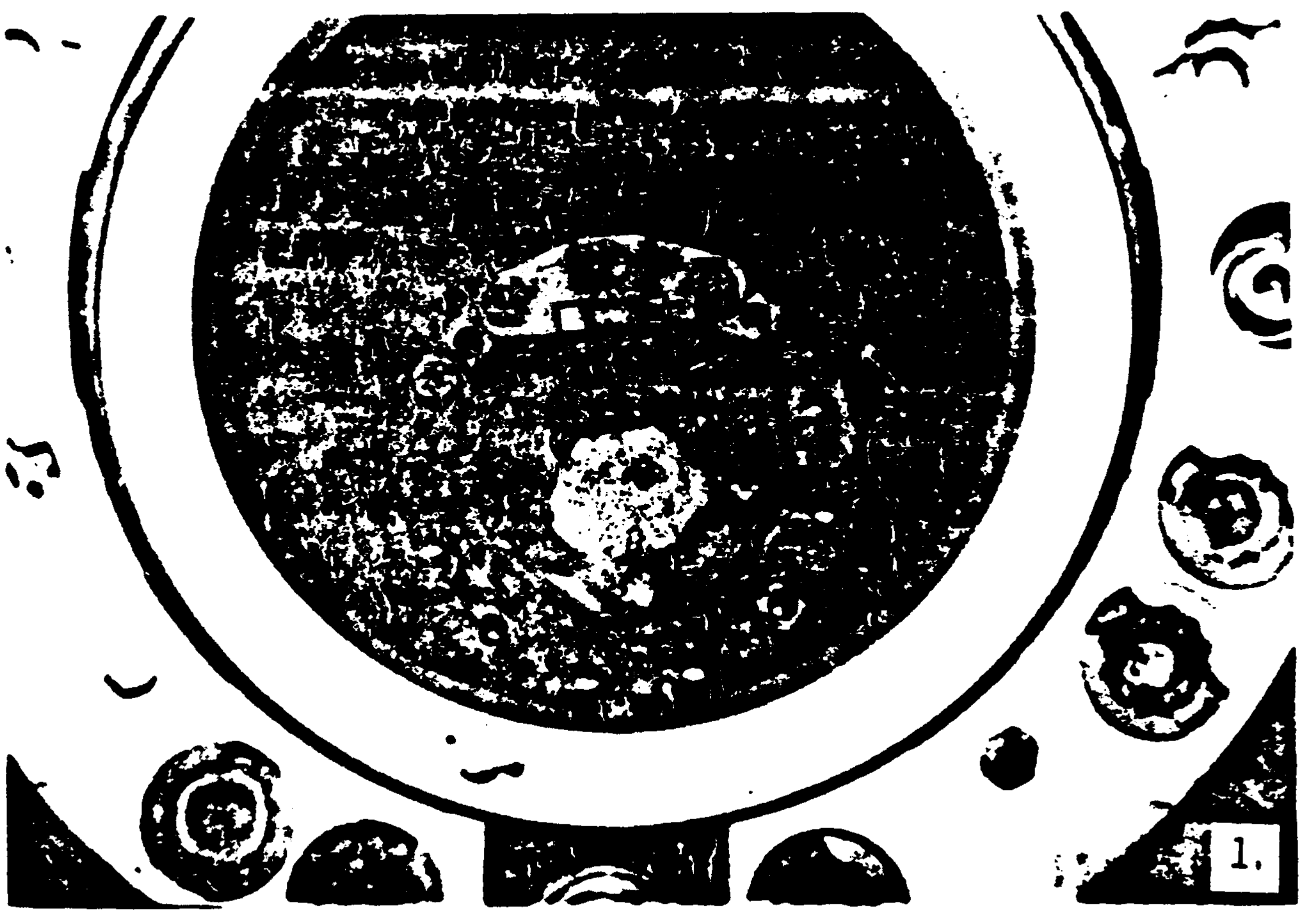
Photograph 9 - Water Integrity Test

This is the Naval wash facility at New River, NC (Camp Lejuene). One Army aircraft was run through to check for leaks. This rig pumps 500 gallons per minute at 200 psi of pressure. Other Army aircraft will be run through at some future time for leak testing.

Photograph 10 - Water Intrusion [not included]

This shows the aircraft with typical leaks. [Water is dripping under and around entry door seals into aircraft interior.]

These field visits have been beneficial and more are planned. Photographic evidence has resulted in considerable corrective action. The Tri-service Corrosion Preventive Advisory Board (CPAB) has made a considerable contribution. With new aircraft the same type of examinations and inspections will be applied. Hopefully NDT/NDE methods will be developed to detect the corrosion long before failures occur so that costly rework can be prevented.



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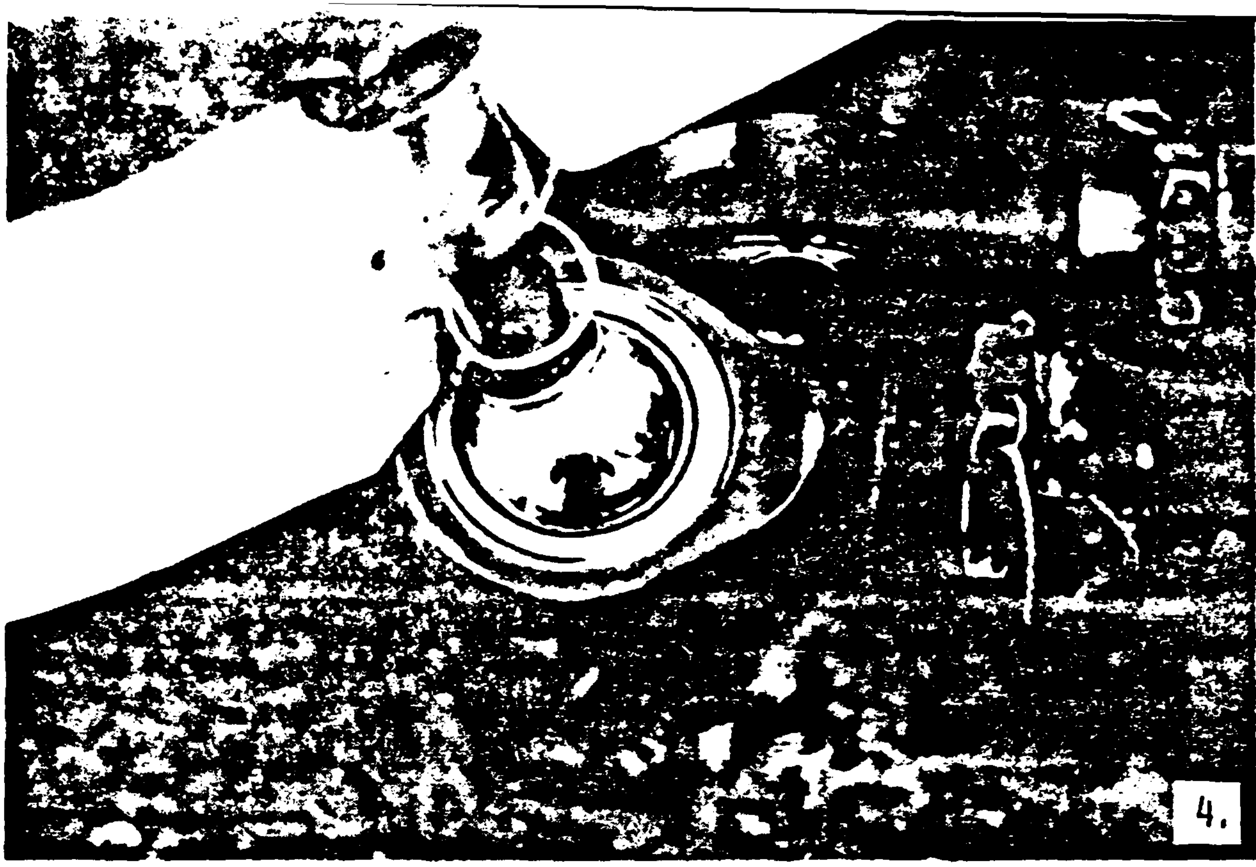

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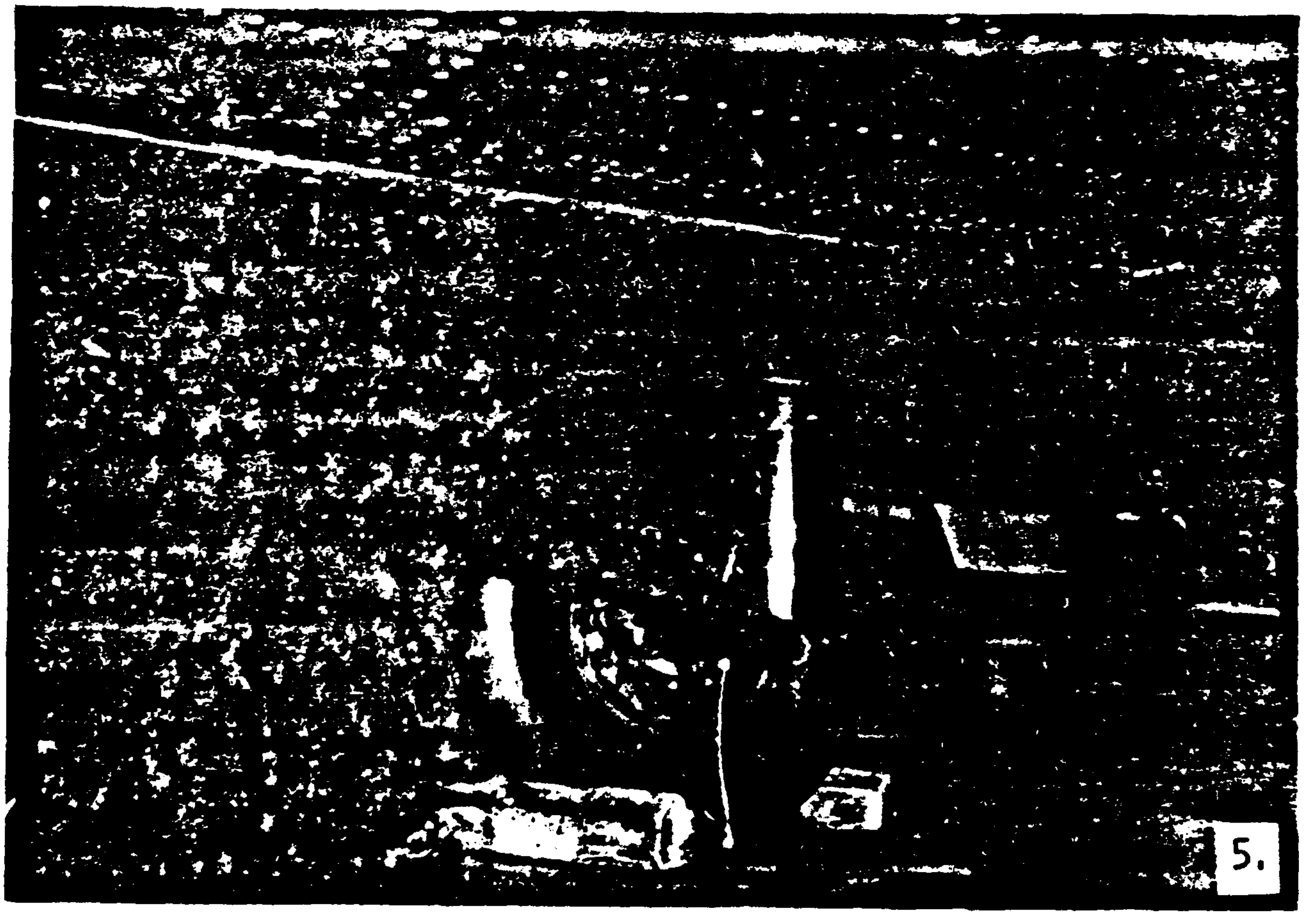

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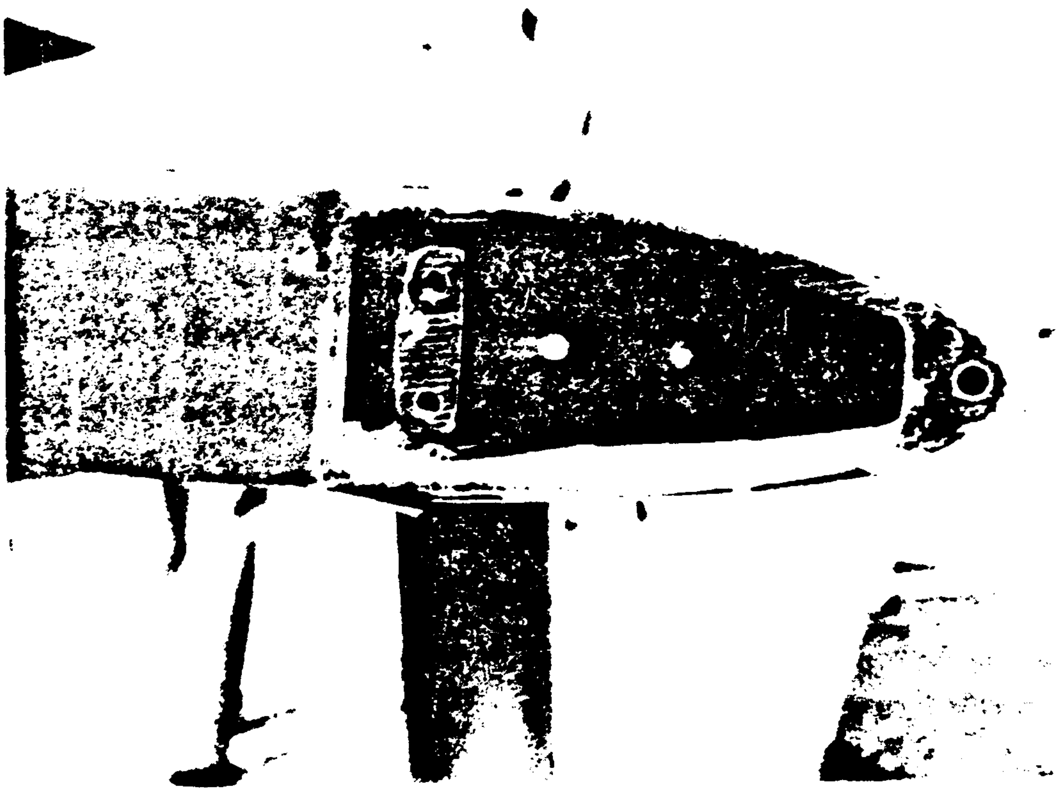

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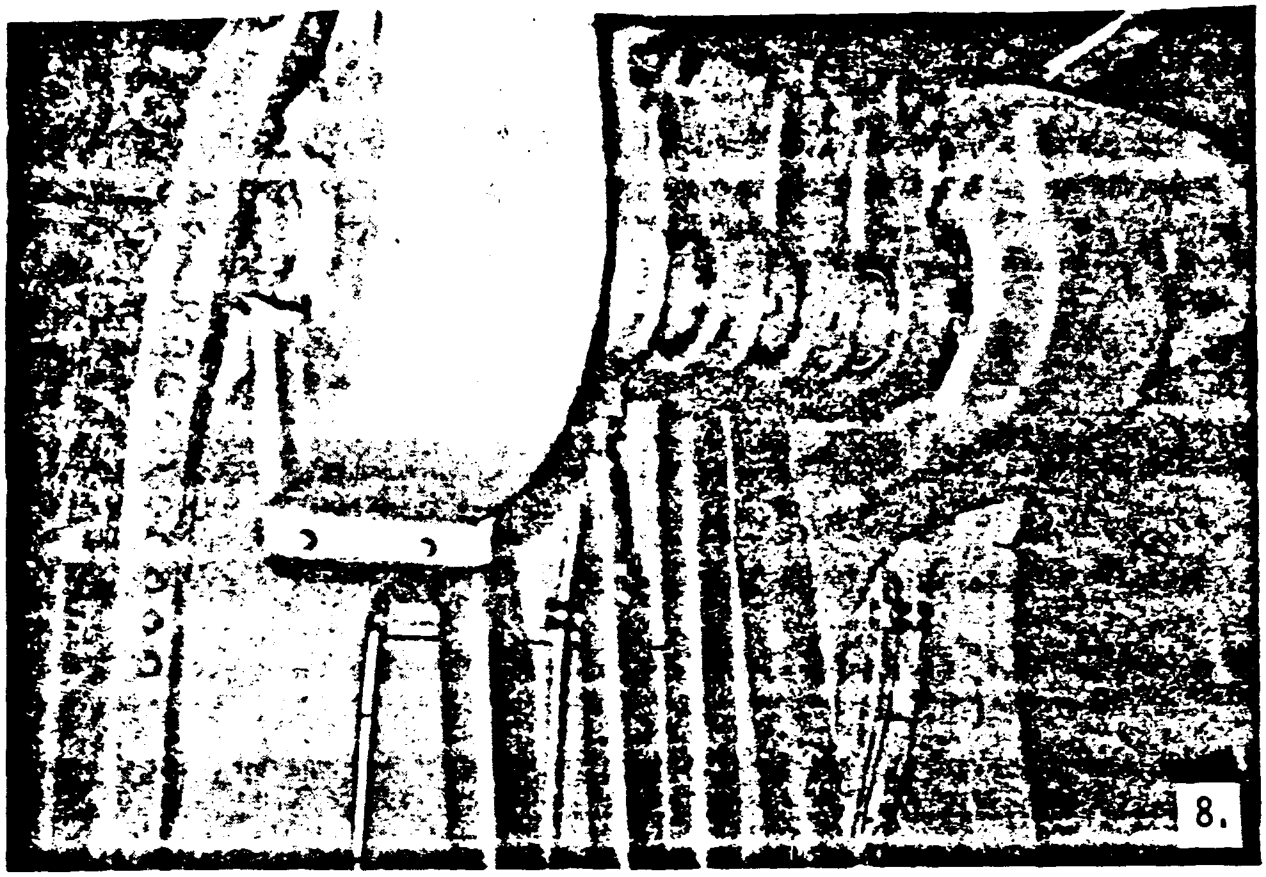


8.

9.

NAVAL AVIATION
DETECTION OF CORROSION BY NDI PROCEDURES

by E. C. (Ed) Holland
Naval Air Systems Command
Washington DC

Despite the preventative measures taken by Navy contractors and service personnel, deterioration of Naval aircraft is a continuing problem. The culprit is the different environments in which the aircraft operate. Corrosion rates experienced by many aircraft in a carrier environment are many times greater than predicted by seashore tests. [Viewgraph 1 - "Naval Aircraft Subjected to the Elements" showed salt spray coming over bow of an aircraft carrier onto parked aircraft. Ed.]

The Navy, in an effort to control the corrosion problem, wash all squadron aircraft every 14 days to keep them as free as possible from corrosion causing contaminates. All aircraft are subjected to periodic inspections. During the inspection, corrosion discrepancies are corrected and reinspection by a quality assurance representative is performed before the aircraft is released from the corrosion treatment phase. At this time an aircraft corrosion/paint condition code is assigned:

AIRCRAFT CORROSION/PAINT CONDITION CODES [VIEWGRAPH 2]

CODE	DESCRIPTION	MAN-HOURS	NO. OF MEN	SHIFT(S) TO COMPLETE JOB
A+	MINIMAL CORROSION/MINIMAL BARE METAL	0-15	4	1/2 SHIFT
A	MINIMAL CORROSION/MINIMAL BARE METAL	15-30	4	1 SHIFT
A-	MINIMAL CORROSION/MINIMAL BARE METAL	30-50	4	1 SHIFT PLUS 4½ hrs
B+	MODERATE AMOUNT OF CORROSION/GOOD PAINT SYSTEM	50-65	4	2 SHIFTS
B	MODERATE AMOUNT OF CORROSION/GOOD PAINT SYSTEM	65-80	4	2½ SHIFTS
B-	MODERATE AMOUNT OF CORROSION/GOOD PAINT SYSTEM	80-100	4	3 SHIFTS PLUS 1 hr
C+	MODERATE TO HEAVY AMOUNT OF CORROSION/ MODERATE AMOUNT OF BARE METAL	100-115	4	3 SHIFTS PLUS 4½ hrs
C	MODERATE TO HEAVY AMOUNT OF CORROSION/ MODERATE AMOUNT OF BARE METAL	115-130	4	4 SHIFTS PLUS ½ hr
C-	MODERATE TO HEAVY AMOUNT OF CORROSION/ MODERATE AMOUNT OF BARE METAL	130-150	4	4 SHIFTS PLUS 6½ hrs
D	EXCESSIVE AMOUNT OF CORROSION/EXCESSIVE AMOUNT OF BARE METAL	150 PLUS	4	5 SHIFTS PLUS

All Navy aircraft are inspected for intergranular, galvanic, filiform, pitting, and surface corrosion. Typical examples of the components inspected, results and limitations are as follows:

Example #1: H-46 Rotor Blade Spar [Viewgraph 3]

A. NDI method: X-ray
B. Type of corrosion: Galvanic
C. Corrosion prone areas: Spar backwall, interior of spar, STA 286
D. Material: 4340 steel
E. Maintenance level: IMA and Depot[1]
F. Limitations of present method: Component must be removed from aircraft and forwarded to IMA for examination.
G. Goal for new equipment: Inspection of the component on the aircraft

Example #2: H-46 Engine Exhaust Device [Viewgraph 4]

A. NDI method: Ultrasonics
B. Type of corrosion: Galvanic
C. Corrosion prone area: Mounting flange
D. Material: Aluminum and stainless steel
E. Maintenance level: Depot

Example #3: H-46 Stub Wing [Viewgraph 5]

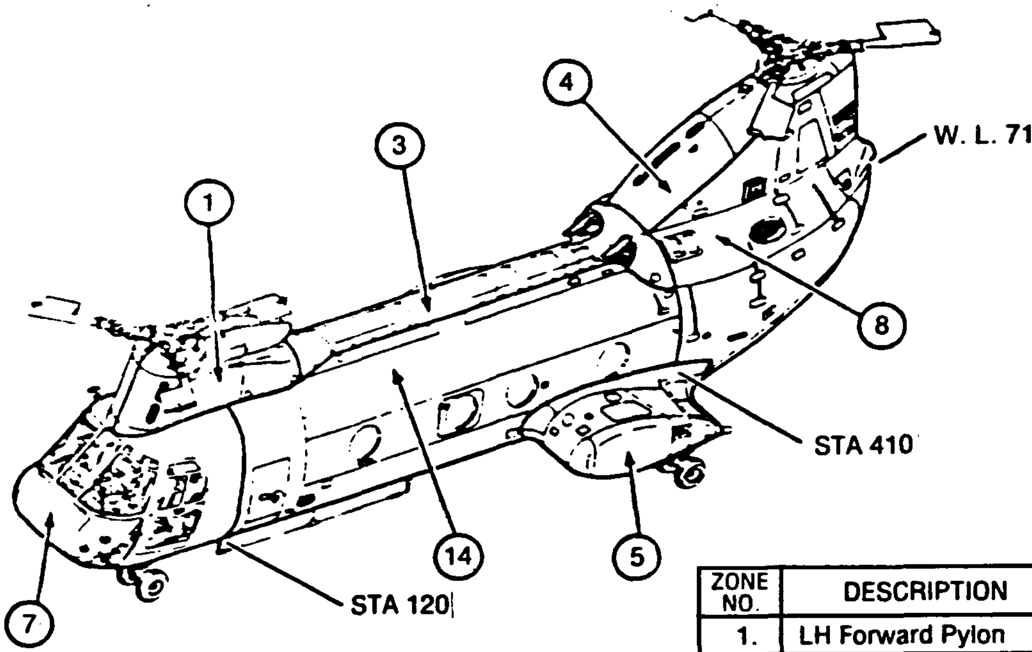
A. NDI method: Eddy current
B. Type of corrosion: Multiple mechanisms
C. Corrosion prone area: Stub wing fittings
D. Material: Aluminum
E. Maintenance level: IMA and depot

Example #4: H-46 and H-53 Drive Shaft [Viewgraph 6]

A. NDI method: Ultrasonics
B. Type of corrosion: Exfoliation
C. Corrosion areas: Drive shaft
D. Material: Aluminum
E. Maintenance level: IMA and depot

---

[1]Maintenance codes: O = OMA = organizatonal maint. activity (components remain on aircraft, shore and afloat); I = IMA = intermediate maint. act. (components off aircraft, ashore and afloat); D = Depot (Naval Air Rework Facility, NARF) maint.



ZONE NO.	DESCRIPTION
1.	LH Forward Pylon
3.	Tunnel
4.	Canted Deck
5.	LH Stubwing
7.	Nose
8.	LH Aft Pylon
14.	LH Fuselage

IDENTIFICATION OF INSPECTION ZONES - H-46

Viewgraph 7 [above] will let you see the areas discussed in the three previous examples, specifically locations 8, 5, and 3 in that order.

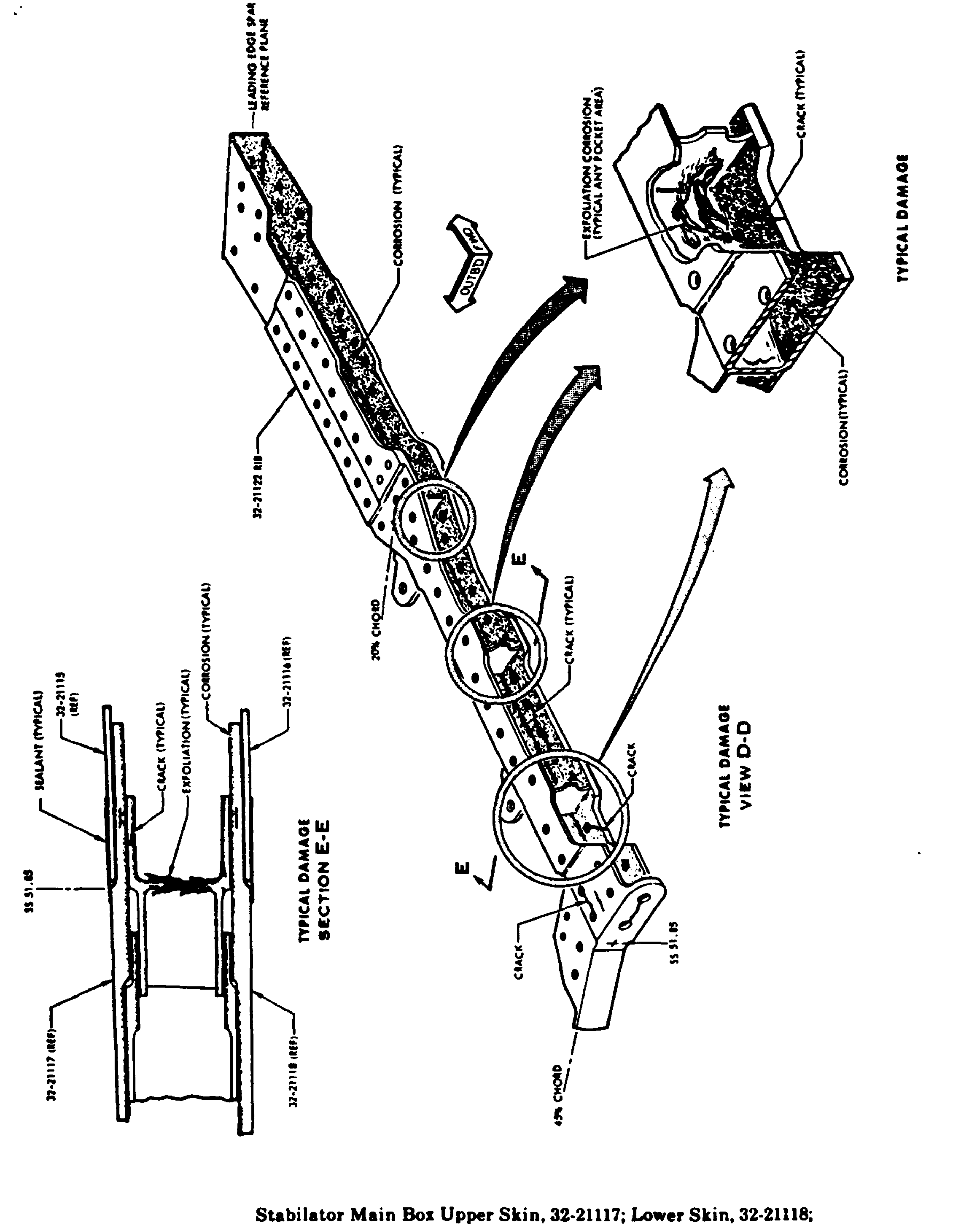
Example #5: Landing Gear on Many Aircraft [Viewgraph 8]

A. NDI method: Ultrasonics
B. Type of corrosion: Exfoliation/Pitting
C. Corrosion prone area: Inside surface of nose landing gear telescopic mechanism
D. Material: Steel
E. Maintenance level: IMA and depot

Example #6: F-4 Stabilator Rib [Viewgraph 9]

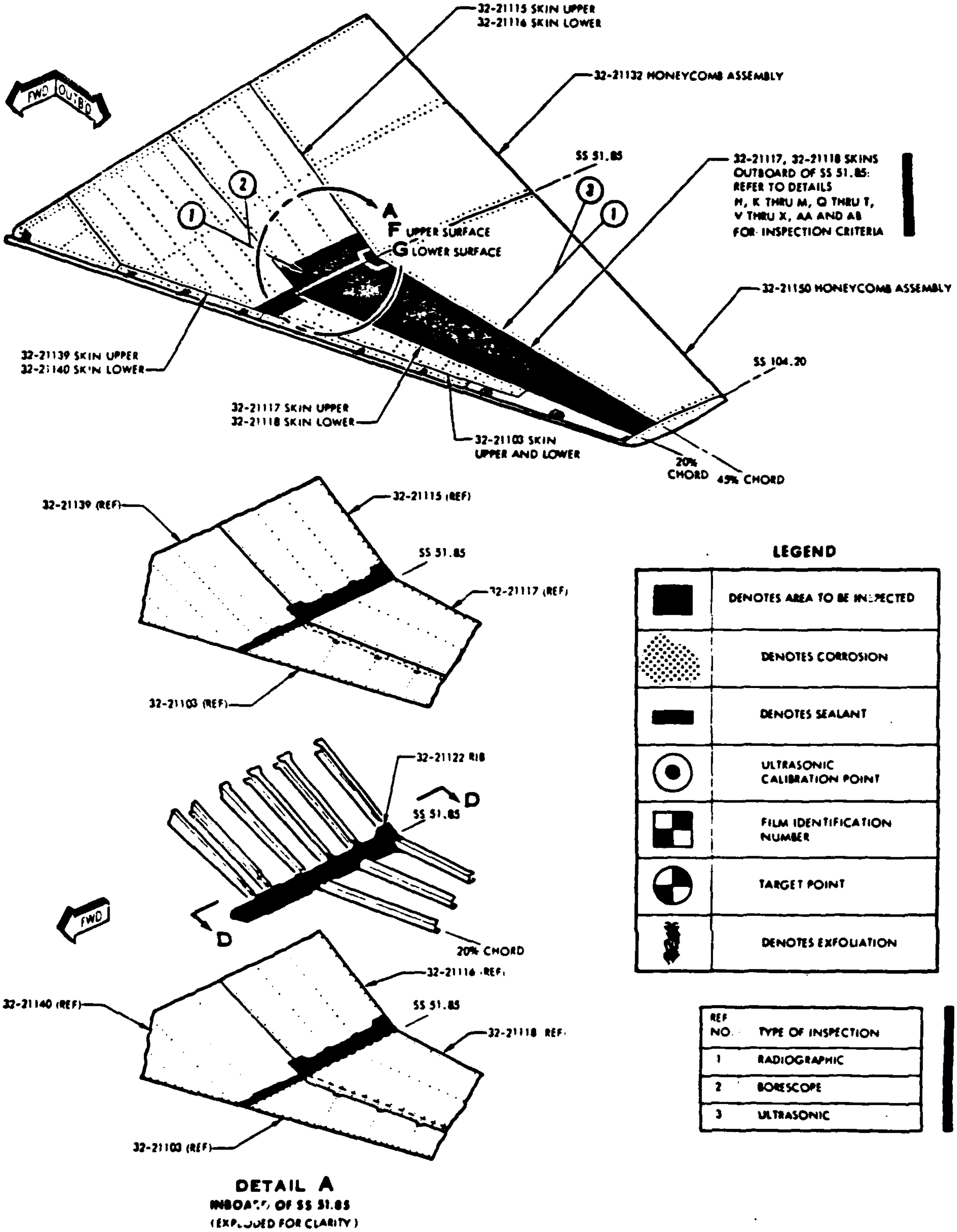
A. NDI method: X-ray
B. Type of corrosion: Intergranular
C. Corrosion prone area: Center rib
D. Material: 7075 aluminum alloy
E. Maintenance level: IMA and depot
F. Limitations of present method: Stabilator must be removed if weather conditions will not permit inspections.
G. Goal for new equipment: Truck-mounted, all-weather x-ray imaging system

Viewgraph 10 [next page] shows where the damage occurs. Also, it was discovered by an "I" level NDI technician that this corrosion was more easily detected using 60°, 90°, and 120° exposures rather than the lone 90° exposure called for in the maintenance instruction manual.



Stabilator Main Box Upper Skin, 32-21117; Lower Skin, 32-21118;

VIEWGRAPH 10



REF NO.	TYPE OF INSPECTION
1	RADIOGRAPHIC
2	BORESCOPE
3	ULTRASONIC

Stabilator Main Box Upper Skin, 32-21117; Lower Skin, 32-21118; and Rib, 32-21122

VIEWGRAPH 12

Example #7: F-4 Stabilator Skin [Viewgraph 11]

A. NDI method: X-ray and Ultrasonics
B. Type of corrosion: Exfoliation
C. Corrosion prone area: Skin
D. Material: 7075 aluminum
E. Maintenance level: IMA and depot

Here [in Viewgraph 12, previous page] you can see the points of interest of examples 6 and 7. Also note in the legend that ultrasonics and borescopes are used successfully in detecting corrosion in this structure. The borescopes are used through holes [from which fasteners have been removed]. It has been found that medical ophalmoscopes otoscopes, used for human ear scanning, similarly applied through fastener holes, are very effective in finding internal corrosion. All Navy/Marine NDI labs are now equipped with ophalmoscopes otoscopes.

Example #8: H-1 and H-2 Main Rotor Blade [Viewgraph 13]

A. NDI method: Ultrasonics, Harmonic bond tester
B. Type of corrosion: Pitting
C. Corrosion prone area: 540 series blades - Spar
   204 series blades - Doubler and Spar
D. Material: Stainless steel or cobalt alloy abrasion strips and aluminum doubler and spar.
E. Maintenance level: This inspection is Depot level; however, some "I" level NDI technicians have been trained and qualified by the depot.

[Viewgraph 14, not included] This is the scarf joint of the H-1 main rotor blade, with the abrasive strip peeled back. The arrows point to the corrosion effected aluminum spar. This damage originated by the loss of a very small amount of sealant in the abrasive strip, resulting in moisture induction and entrapment.

Viewgraphs 15, 16, 17 [not included] show laboratory findings of corrosion in H-1 blades. [Fig. 1 on the following page attempts to show the relevant geometries of the H-1 blades. Ed.]

Limitations of Current Test Procedures

- In most cases, components must be removed for aircraft to be examined
- Corrosion must be fairly advanced before it can be detected by current NDI methods
- Test equipment is manually operated and subject to operator interpretation
- Lack of permanent record
- Paint stripping required with some methods
- Reinspection method slow
- Usually only small area can be inspected at one time

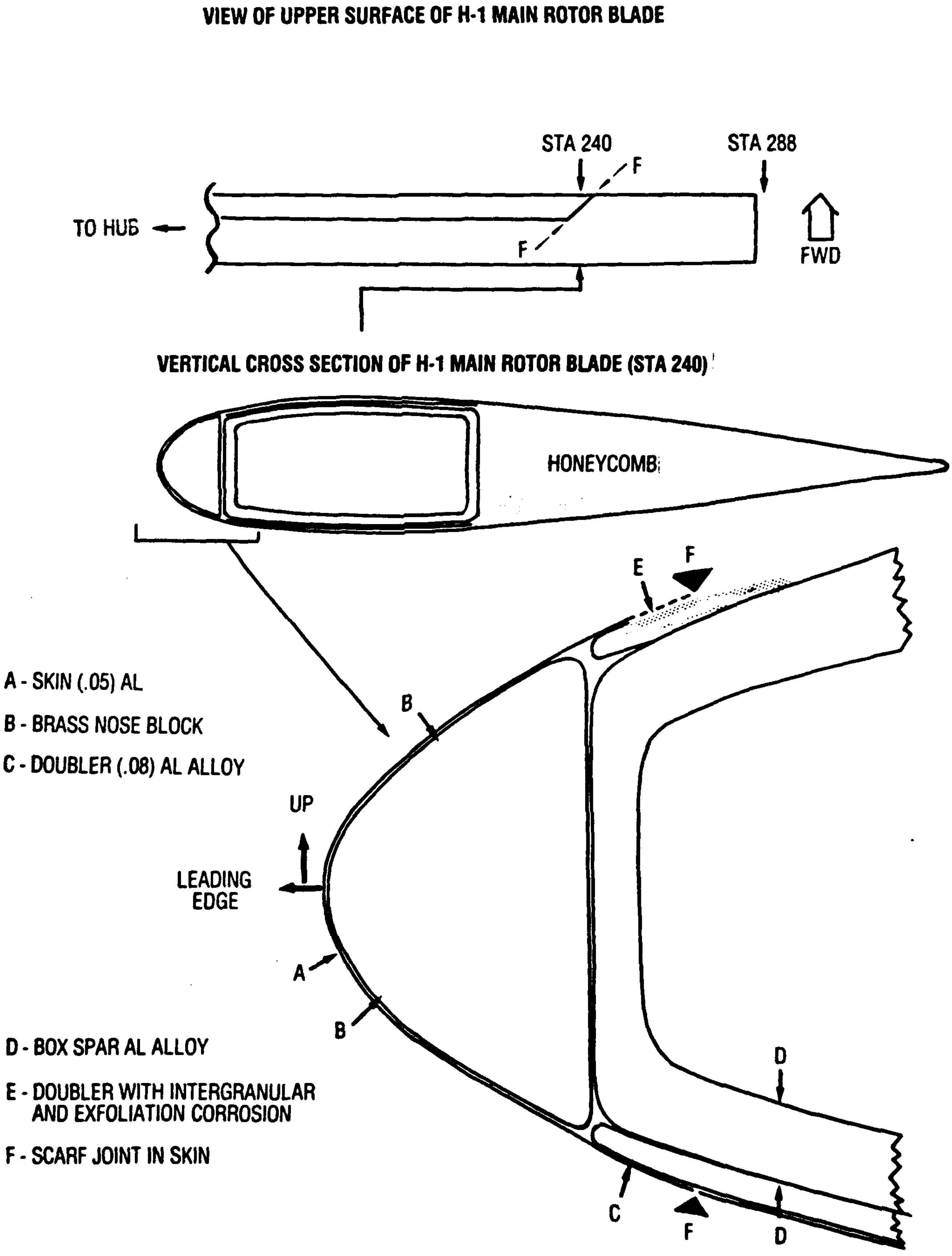


FIG. 1 H-1 MAIN ROTOR BLADE

Mutual Generic Corrosion Problems

- Exfoliation and debonding on aluminum skin/aluminum honeycomb
- Corrosion at joints despite sealing
- Surface corrosion of skin
- Pitting-wing leading edges, etc.
- Filiform corrosion
- Limited inspection capabilities at operational levels
- Problem is labor intensive and requires costly disassembly
- NDI procedures are weather sensitive
- Corrosion of wiring and electronic equipment

Current and Future Research and Development Programs

- Advanced NDT practices - Evaluate and develop new or improved NDT techniques having applicability to new and existing problems
- NAVAIR participates in the advisory group for aerospace research and development (AGARD) corrosion fatigue testing
- X-ray collimator development (to allow x-ray aboard ship) - Function will be to attenuate radiation leakage during radiographic inspections
- Automatic shipboard film processor (will expedite film processing aboard ship)

Areas With Strong Potential (Awaiting R&D Funding)

- Improved methods for detecting interface corrosion
- Method for reliable detecting corrosion under paint
- Better corrosion mapping procedures - Automatic or semiautomatic
- Real time radiography
- Motion radiography or real time radiography

Long Term Research and Development Programs

- Automated and hard copy readouts
- Portable C-scan equipment
- Neutron radiography
- Phase sensitive eddy current equipment for far side corrosion identification

Of Special Interest

The Naval Air Engineering Center has been tasked by NAVAIRSYSCOM to develop a Program Element Master Plan (PEMP) for all NDI equipment, including corrosion detection equipment. The document will analyze all current/predicted NDI requirements and define a consolidated NDI equipment program. This PEMP effort is considered as the Requirements Document of NAVAIR.

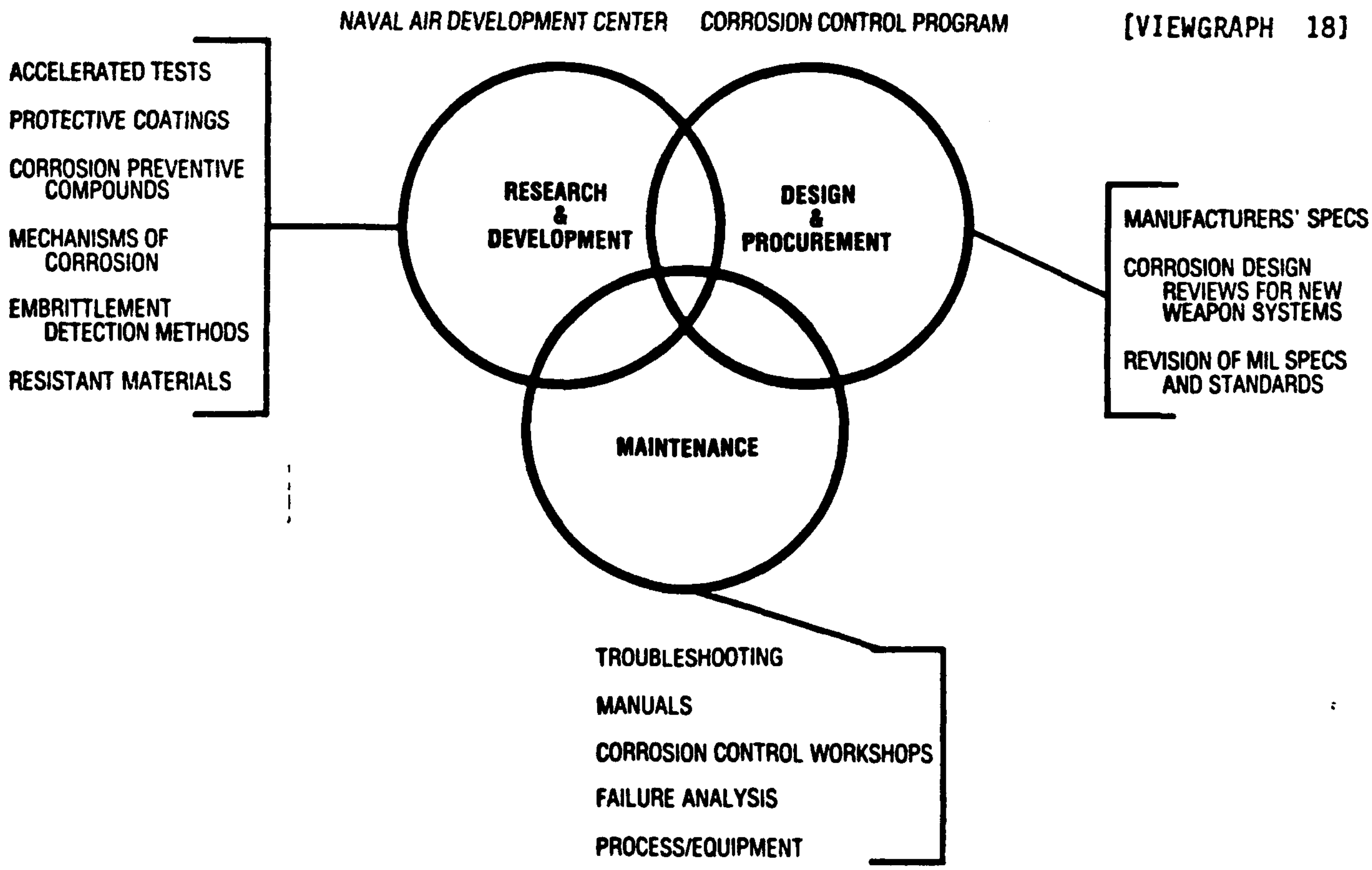
Summary

In summary, I have highlighted some of the corrosion problems that exist in Naval aircraft. I have touched on the limitations of current equipment and methods used in fighting generic corrosion problems, and I have indicated some of the areas requiring R&D.

The Naval Air Systems Command, however, does not depend only on NDI for the solution of corrosion problems. Through programs at the Naval Air Development Center we seek to understand the fundamentals of corrosion and to develop better methods of prevention and maintenance procedures for the correction of corrosion problems.

I want to point out again the unique conditions under which Naval aircraft are subjected. [Repeat Viewgraph 1] Naval Air is very interested in obtaining better methods of detection and correction of corrosion as well as providing the same to others. The Navy Aviation representatives at this Workshop are here to do that as well as assisting in solution of problems common to all.

[VIEWGRAPH 18]



"AIRLINE CORROSION/NDI REQUIREMENTS"

by Mr Peter Opar
Director of Quality Assurance
US Air, Pittsburgh PA

My comments will be associated with the corrosion problems experienced by the airlines providing you with the most critical area first. They will also detail the airlines corrosion control and prevention program and suggest the type of NDI equipment which still needs developed.

I. The corrosion prone areas are:

1. Areas under the galley and lavatory floorboards are subject to the most corrosion due to spilled fluids saturating the floor covering and seeping into the cargo compartments underneath.

The liquids which seep into these compartments and end up in the bilge areas have no means of escape and become trapped resulting in corrosion to the lower fuselage skin, ribs and formers, control cables and lower antenna mountings. [Slides 1, 8, 16, 37]

2. Main entrance and galley service door areas are subject to blowing rain and melted snow conditions.

3. Electrical compartments are usually located in the lower fuselage and contain batteries. This area is subject to corrosion from battery acid, heat from the avionics equipment and condensation.

4. Wheel well areas where sand, dirt, and moisture picked up from the runways become trapped between lower skin and structure.

5. Wing fuel tanks at inboard end where water droplets are trapped between ribs and formers resulting in microbial growth and intergranular corrosion. [Slide 27]

6. Aluminum tubing in the pitot/static and engine indicating lines where moisture becomes trapped at low points in each system. Corrosion starts from the inner surface (pin holes) and results in erroneous instrument readings.

7. Corrosion under painted surfaces at fasteners where paint chips and moisture collects under the paint. [Slide 34]

8. Switches and connectors in the landing gear wells, where they are exposed to water, are subject to heavy corrosion, and affect landing gear indication circuits.

9. Seat tracks exposed to wet carpeting for lengthy periods.

II. The degree of corrosion will vary depending on the environment in which the airline operates. Each airline develops its own corrosion control program to satisfy its own needs. Airlines operating in a salt air atmosphere must have a more stringent program.

A successful program will consist of:

a. Opening and inspecting the corrosion prone areas at scheduled frequency intervals.

b. Conducting a thorough clean-up of all areas.

c. Treating the area with a corrosion inhibiting compound and sealing properly.

III. The airlines need:

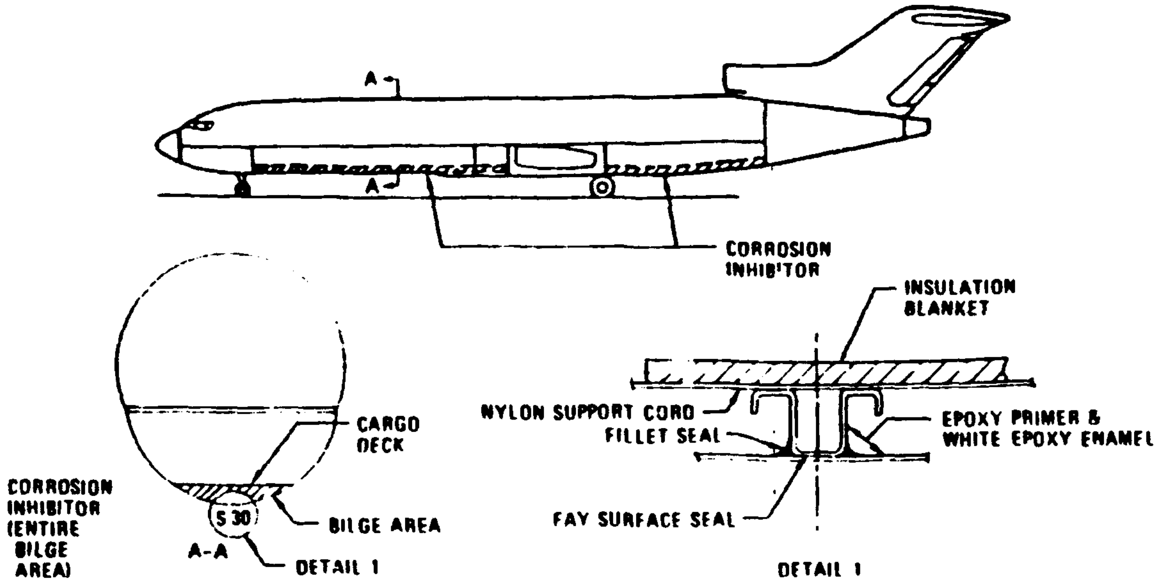
1. NDI equipment which will not just tell us that corrosion is present, but to what degree has the corrosion progressed and which members are corroded.

2. Lightweight, small head x-ray and video monitoring system which can be guided into small areas for instant inspection.

3. Donut shaped probes for in-situ inspection of aluminum tubing.

4. Equipment for detecting corrosion in electrical switches and connectors.

5. Long-lived eddy current pencil probes.

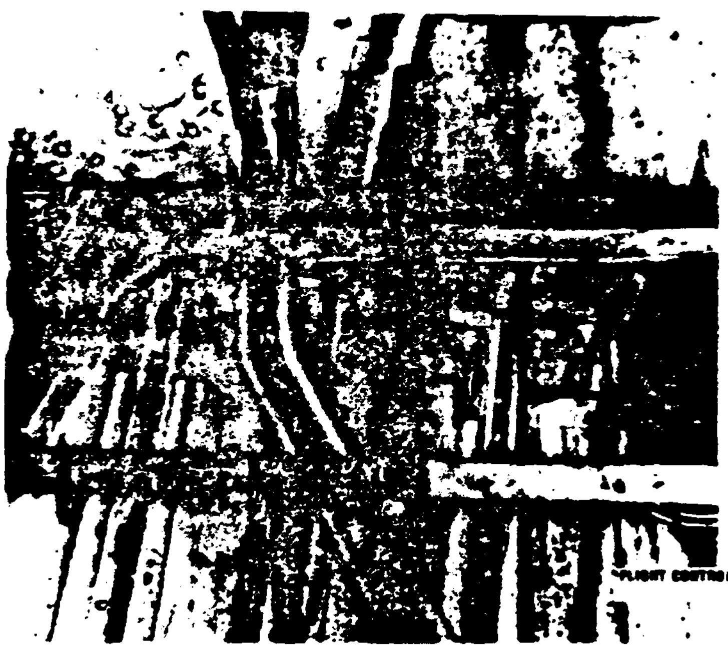


MOISTURE ENTRAPMENT - FUSELAGE

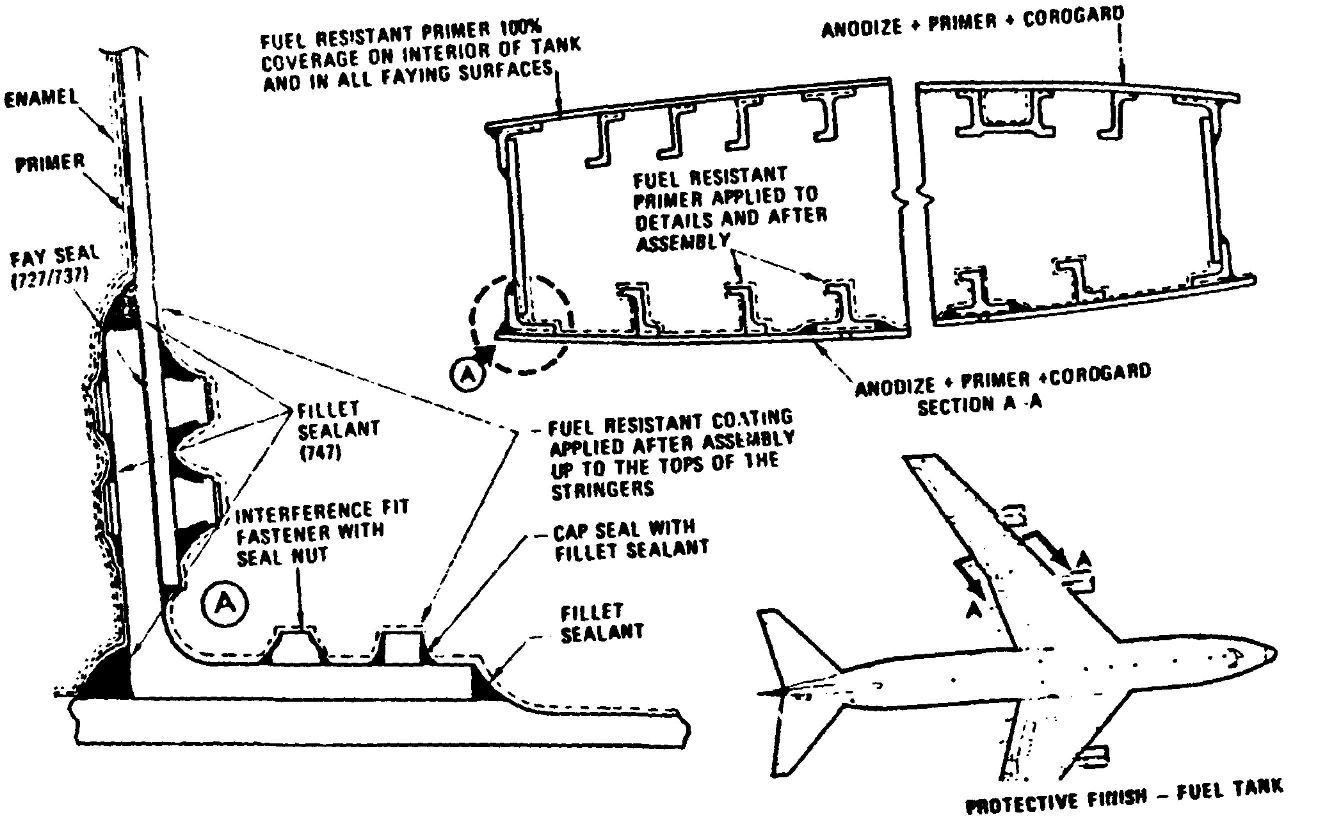
SLIDE 1

SLIDE 8

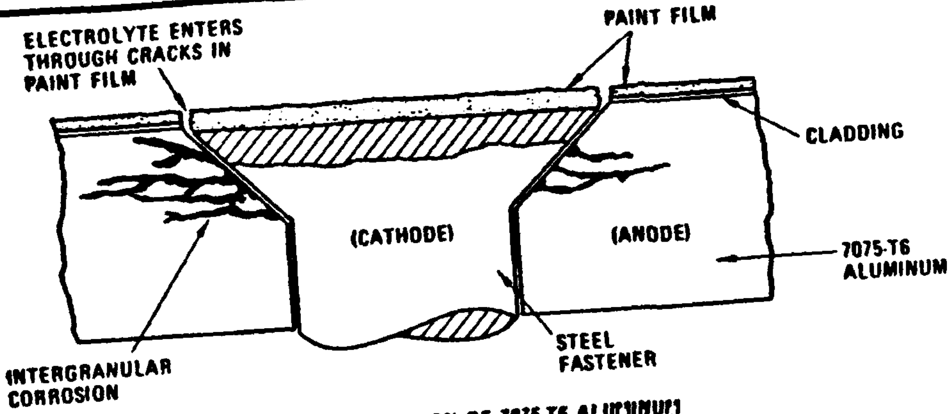
SLIDE 16



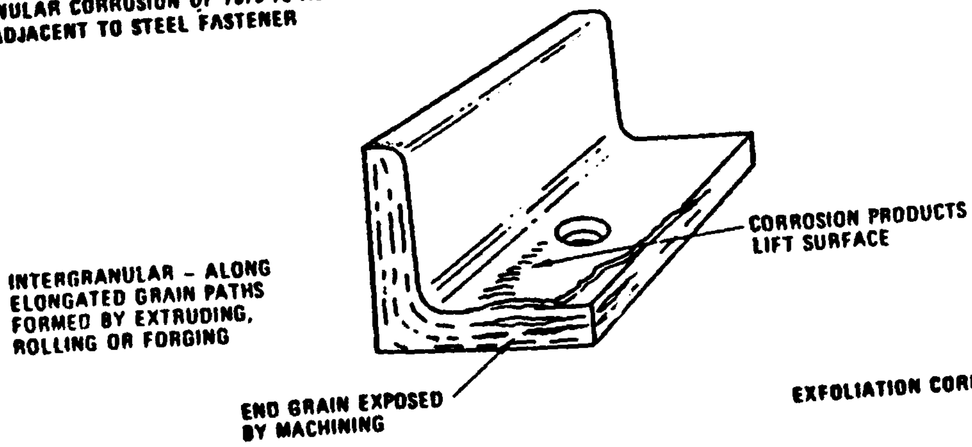
SLIDE 37



SLIDE 27



INTERGRANULAR CORROSION OF 7075-T6 ALUMINUM ADJACENT TO STEEL FASTENER

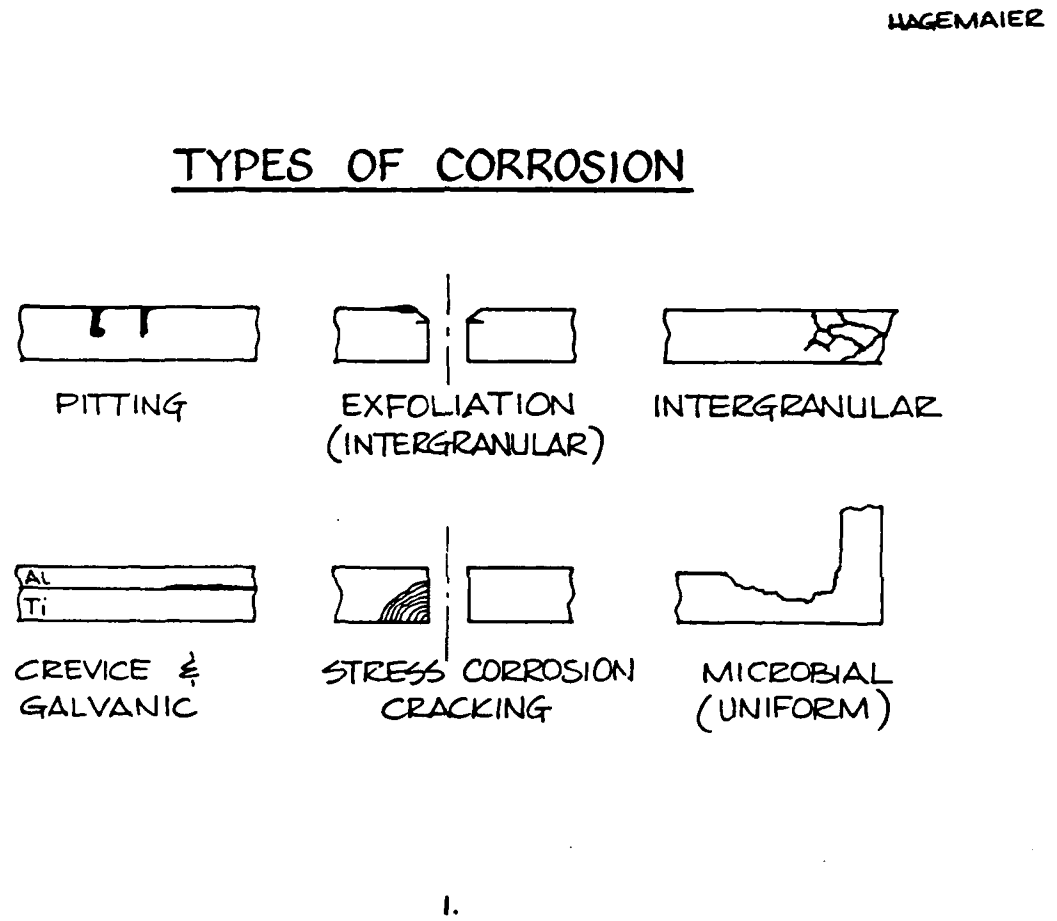


EXFOLIATION CORROSION

SLIDE 34

AIRCRAFT CORROSION AND DETECTION METHODS

by D. J. Hagemaier
Douglas Aircraft Company
Long Beach, CA



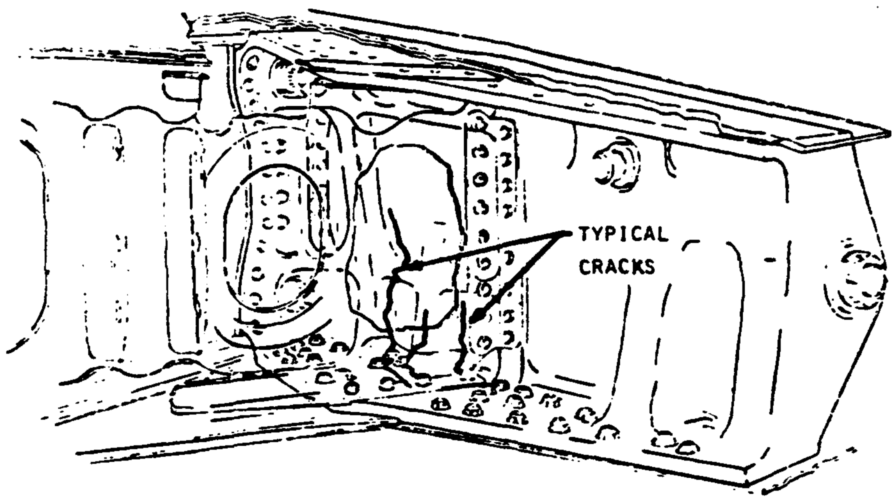
Aircraft Corrosion Problems [Viewgraph 2]

- Stress corrosion cracking of 7075-T6 and 7079-T6 forgings
- Bilges, floor panels, sumps (around toilets and galleys)
- Water intrusion into adhesive bonded laminates and honeycomb panels
- Wing skin exfoliation at fastener holes
- Pitting, corrosion of steel parts
- Microbial corrosion of wing fuel tanks

INSPECTION METHODS:

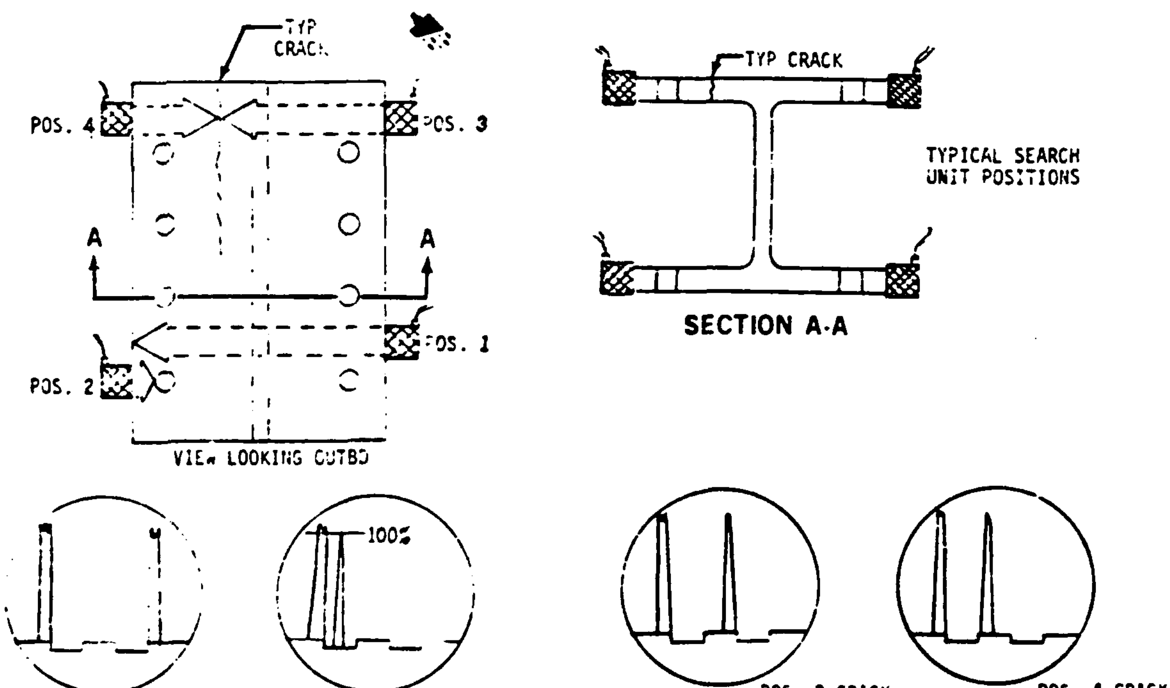
VISUAL

EDDY CURRENT



STRESS CORROSION CRACKING OF 7079-T6 MLG ATTACH FORGING

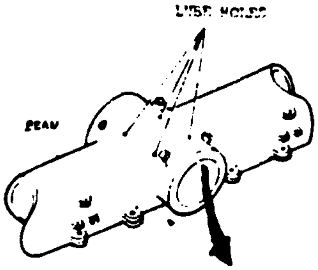
3.



5. ULTRASONIC INSPECTION OF FRAME FORGING FOR STRESS CORROSION CRACKS

HAGLEMAIER

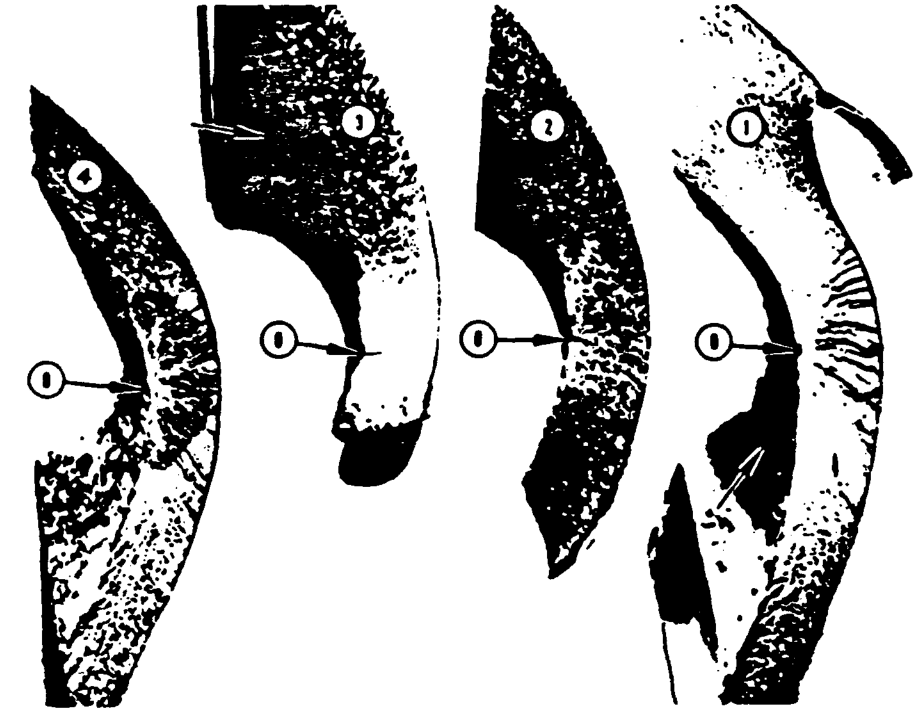
INSPECTION METHOD: VISUAL ENDOSCOPE



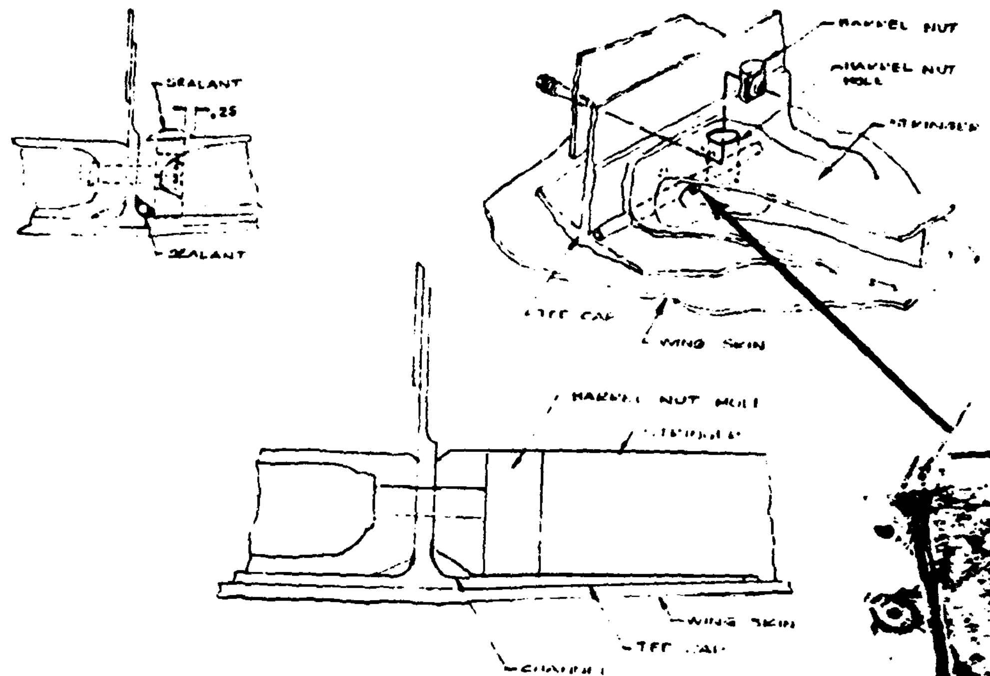
PITTING CORROSION AND STRESS CORROSION CRACK IN 300M STEEL MLG BEAM

8.

HAGLEMAIER

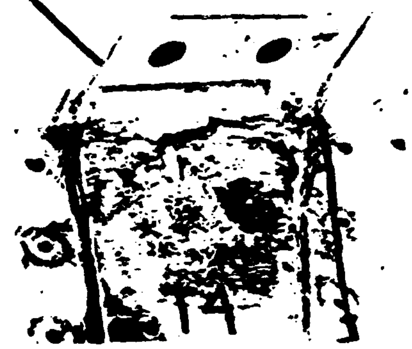


10. THE BRITTLE FRACTURE ORIGINS WHICH INITIATED AT CORROSION PITS ARE LOCATED BY ARROW "0". NOTE THE TYPICAL SEVERE PITTING CORROSION IDENTIFIED BY THE UNMARKED ARROWS.

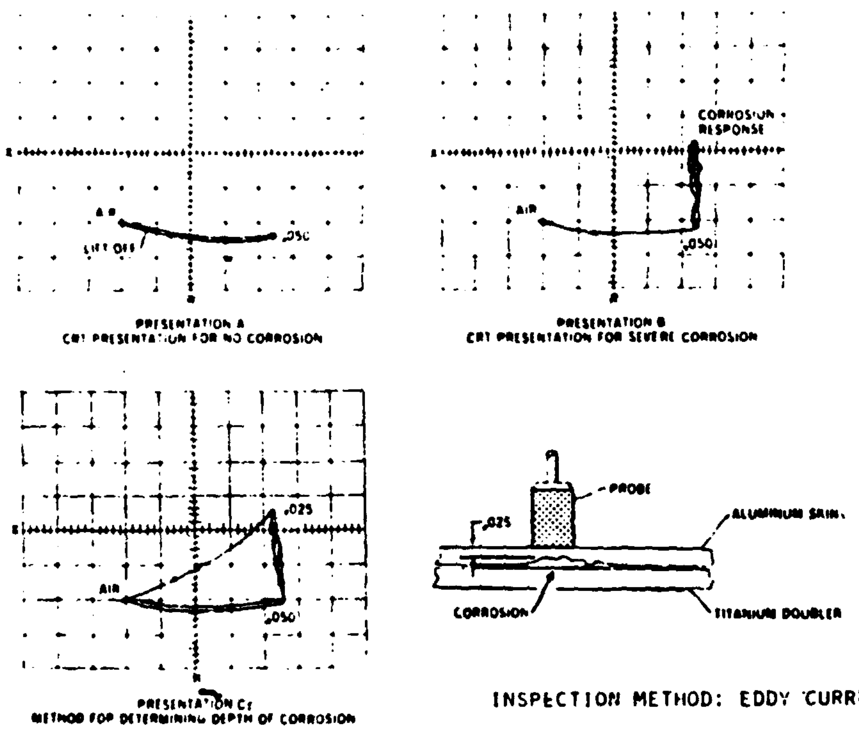


SCHEMATIC OF TEE CAP AND STRINGER ASSEMBLY

13.



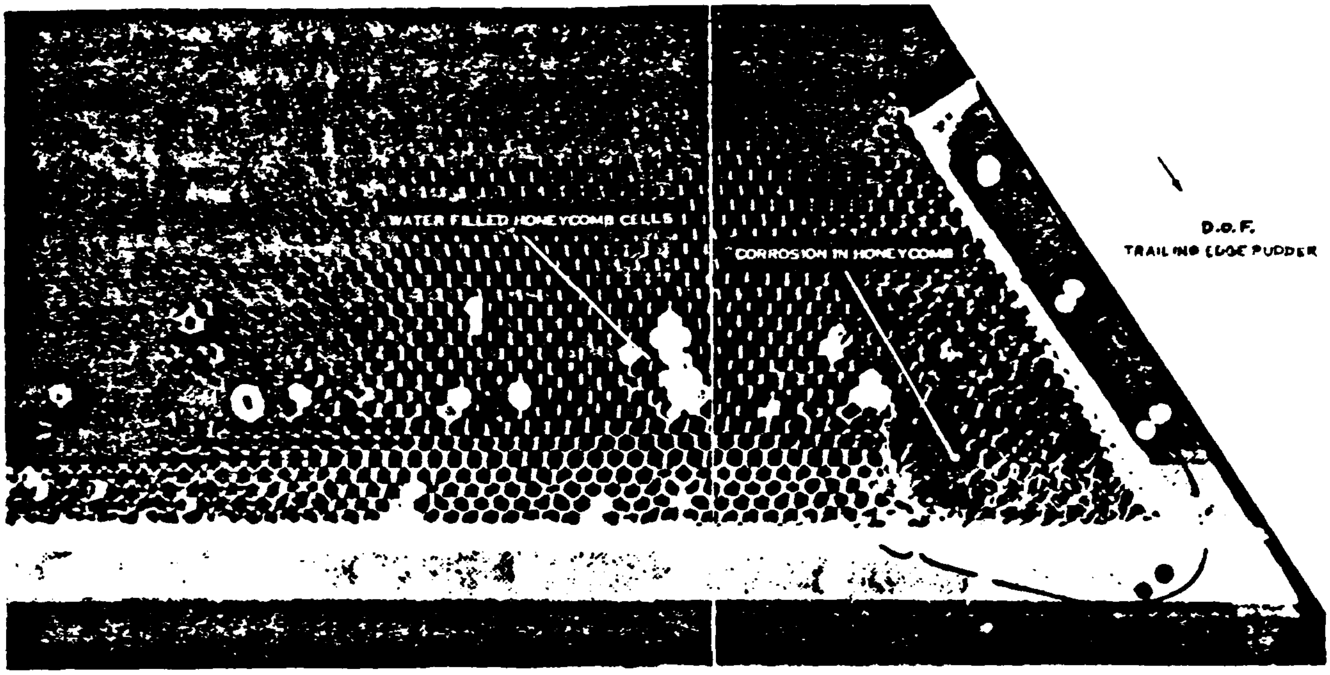
MICROBIAL CORROSION OF 7075-T6
TEE CAP BELOW STRINGER 12.



INSPECTION METHOD: EDDY CURRENT

17. IMPEDANCE PLANE CRT PRESENTATIONS FOR CORROSION THINNING

INSPECTION METHOD: X-RAY RADIOGRAPHY

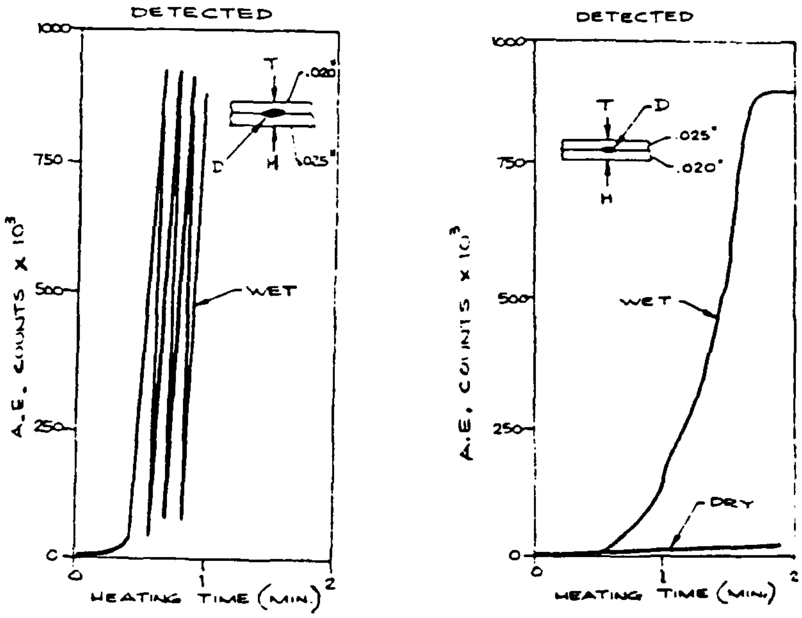


CORROSION OF ALUMINUM HONEYCOMB CORE BY WATER INTRUSION

18.

INSPECTION METHOD: X-RAY

19. POSITIVE X-RAY RADIOGRAPHS OF CORRODED ADHESIVE BONDED LAMINATE



NOTES:

T = TRANSDUCERS
H = HEAT
D = DEFECT

95 DB GAIN
NO FILTER
165 KHz
200F

ACOUSTIC EMISSION TESTING OF CORRODED LAMINATE

23.

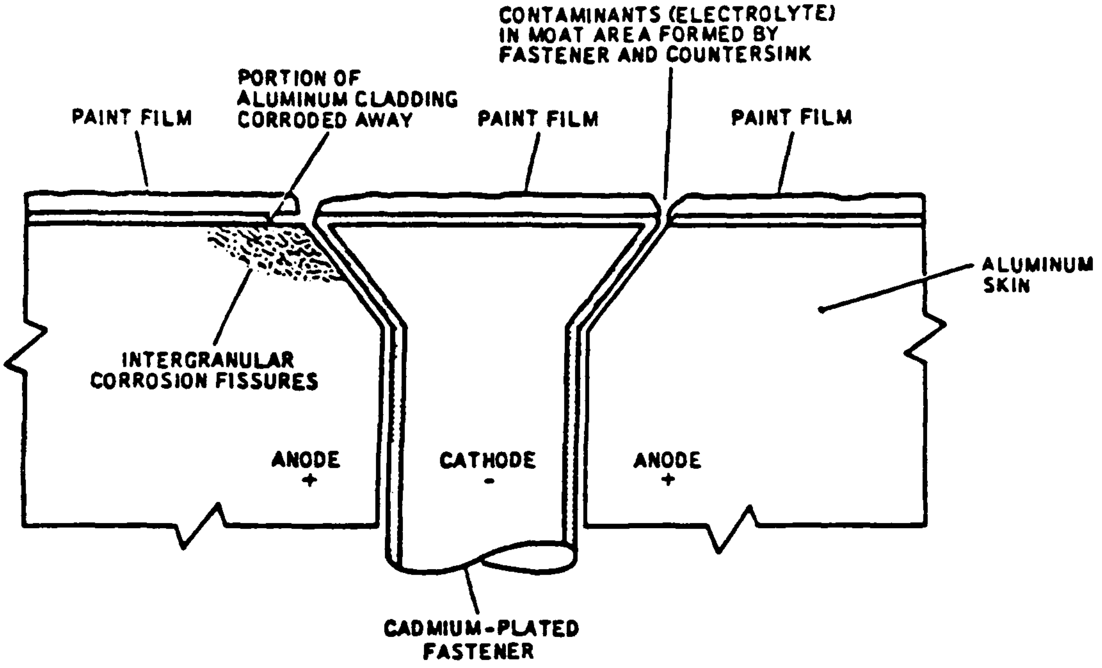
Based on preceding data, the following conclusions can be made concerning the NDI of corrosion delaminated adhesive bonded laminate:

1. Fokker, harmonic, and 210 bondtesters clearly outlined the corrosion delamination in the wet or dry condition.

2. X-ray radiography clearly detected the wet or dry interface corrosion.

3. Acoustic emission only detected wet interface corrosion delamination. To detect wet interface corrosion, the transducer must be located over the defective area.

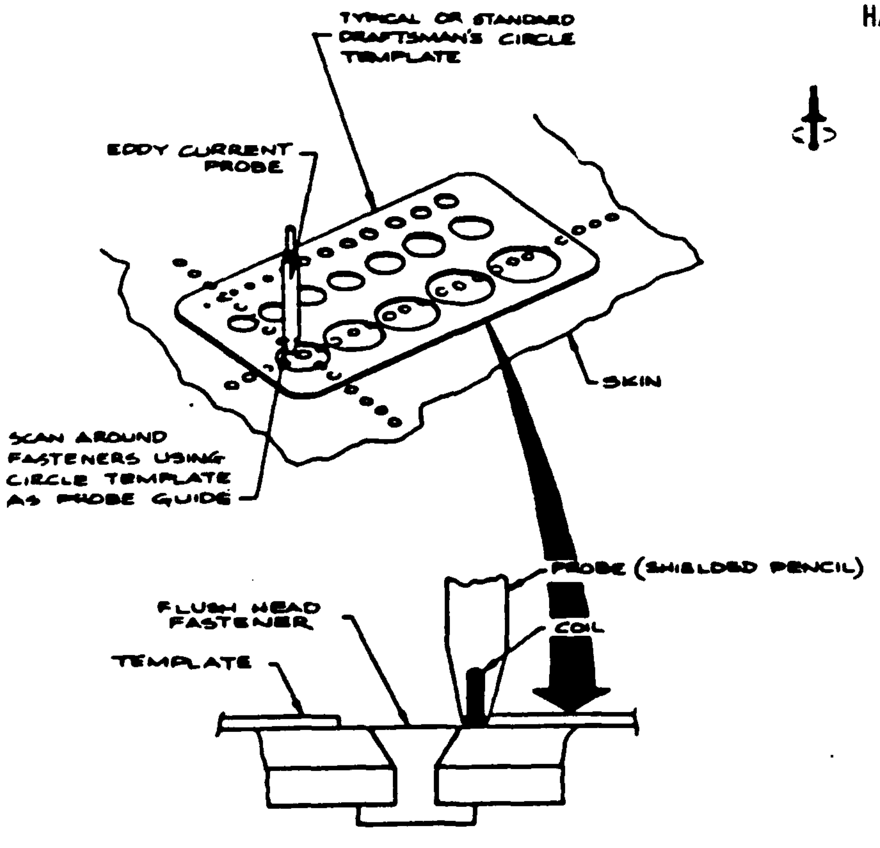
[Viewgraph 24]



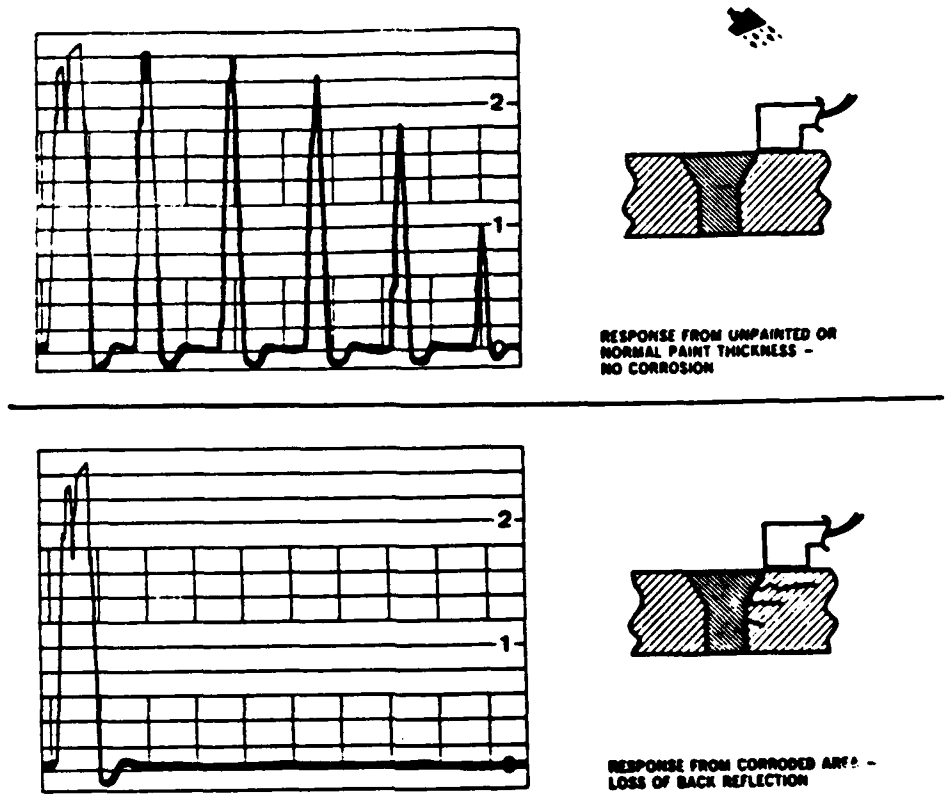
GALVANIC ASPECTS OF CORROSION

25.

HAGEMAIER



29. EDDY CURRENT SCANNING AROUND FASTENERS USING CIRCLE TEMPLATE AS PROBE GUIDE



CONTACT ULTRASONIC CRT RESPONSES

31.

Corrosion Inspection Requirements [Viewgraphs 34,35]

1. Unless proper inspection and maintenance are systematically performed, corrosion can seriously damage the airplane. All aircraft should be carefully inspected for signs of corrosion at each scheduled inspection period. Severe environmental conditions such as salt spray, humidity, and temperature may require increased frequency of corrosion inspections. In addition, areas most susceptible to corrosion should be inspected at frequent intervals.

2. The first appearance of corrosion on unpainted surfaces is in the form of white powder or spots. Areas where sand, dirt, and grime collect are particularly susceptible to corrosion. In conducting inspections for corrosion, particular attention must be given to the underside of the fuselage, upper surfaces of wings, wing flaps, ailerons, and actuating mechanisms. Areas subjected to battery electrolyte and exhaust gases require close attention and frequent maintenance.

3. There will be less corrosion on painted, plated, or aluminum clad surfaces than on unprotected surfaces. However, corrosion will attack protected metal as moisture and contaminants permeate the barrier coat when it has been damaged. In such cases, the affected areas are generally characterized by a scaly or blistered appearance, or sometimesby discoloration of the paint. Corrosion on aluminum alloys and plated steel surfaces can often be recognized by dulling or pitting of the area, and sometimes by white or red powdery deposits.

4. In making inspections on interior surfaces and lap joints, particular attention must be given to areas and sections where foreign matter or moisture may accumulate. Areas underneath floor panels, and faying surfaces which entrap moisture require frequent inspection. Special inspection is recommended in areas where magnesium alloys are used. Areas where dissimilar metals are used require close inspection.

5. Organic materials such as sponge rubber, soundproofing, and insulated materials can retain moisture. The extent of corrosion of metal in contact with organic material can be determined by tests and visual inspection. A sharp-pointed instrument to discover corrosion in contacting metal should be accomplished with care to avoid further damage.

Preventive Maintenance Procedures for Corrosion Control

Cleanliness through frequent washing is the best approach for corrosion prevention. Clean, dry air will not corrode metals at a destructive rate. Corrosion problems are caused by moisture and contaminants, such as exhaust gases, waste water, and salt water encountered in service.

Corrosion Detection and Control [Viewgraph 36]

- Corrosion detected visually or by part failure
- Reported to manufacturer (colored photos or failed parts)
- Failure analysis conducted
- Specific inspection method developed or defined
- Corrective action defined by manufacturer
- Inspection implemented by operator and results reported
- Corrective action performed by operator
- Closing action - repair or modification

Gaps in Present NDE Technology [Viewgraph 37]

1. Specific inspections used for each case of corrosion based on:
   - Type of corrosion
   - Location on aircraft
   - Access to corroded area
   - NDI techniques available to operator
   - Severity of corrosion
2. Corrosion initiation or small areas of corrosion are difficult to detect.
3. Most NDI technicians have not been trained in corrosion detection.
4. Many NDI engineers are not familiar with corrosion detection methods.

HAGEMAIER — 38.

DETECTION METHODS	EQUIPMENT					
	SIZE	MOBILITY	AUTOMATED	SPEED	COST	AVAILABILITY
VISUAL	SMALL	GOOD	NO	FAST	LOW	YES
TAP TEST	SMALL	GOOD	POSSIBLE	FAST	LOW	YES
ULTRASONIC	MEDIUM	GOOD	POSSIBLE	MODERATE	MODERATE	YES
EDDY CURRENT	SMALL TO MEDIUM	GOOD	POSSIBLE	MODERATE	MODERATE	YES
X-RAY RADIOGRAPHY	MEDIUM TO LARGE	FAIR	NO	SLOW	HIGH	MOST SHOPS
NEUTRON RADIOGRAPHY	LARGE	POOR	NO	SLOW	VERY HIGH	RARE
*ACOUSTIC EMISSION WITH HEAT	MEDIUM	FAIR	NO	MODERATE	MODERATE	VERY FEW SHOPS

* PARTS MUST BE REMOVED FROM AIRCRAFT FOR TEST.

Editor's Note: The following viewgraphs were omitted due to space constraints:

Number	Title
4	Stress corrosion cracking of 7075-T6 frame forging
6	Belly corrosion
7	Belly corrosion
9	The spoiler torsion bars are shown, as received. Note they all failed in a similar pattern.
11	X-ray positive print showing pits in torque tube ID and voids in sealant
14	Corrosion inspection of Tee-Cap under stringer [by x-ray and neutron radiograph]
15	Crevice and galvanic corrosion of fuselage skin
16	CRT calibration for 0.050-inch-thick skins
20	Visual confirmation of corrosion delamination after NDI
21	Acoustic emission detection of water intrusion into adhesive bonded honeycomb and corroded laminates
22	Acoustic emission test of corroded adhesive bonded laminate
26	Photomacrograph of blistering produced by exfoliation at attach hole with fasteners installed
27	Surface manifestation of subsurface corrosion around installed fasteners
28	Fluorescent penetrant indications of exposed exfoliation corrosion with fastener installed
30	Eddy-current impedance-plane responses for exfoliation corrosion around fastener holes in wing skins
32	Automated ultrasonic C-scan recording system for detection of wing skin corrosion
33	Ultrasonic C-scan recording of wing skin showing exfoliation corrosion around steel fastener
39	"Did you find much corrosion" [cartoon]

CONCURRENT WORKSHOP SESSION:

Problem Selection - Accessible Airframe Corrosion
"Generic Corrosion situations in exterior or accessible airframe locations for which no inexpensive, efficient NDE methods exist"

CHAIRMAN: Mr Grover Hardy
ASSISTANT: Mr James Holloway

Summary (Mr Grover Hardy)

Key technology deficiencies/needs (these nine items are prioritized, most important first):

1. Faying Surface/Stack-Ups
   - Rapid coverage of large areas
   - Improved discrimination between defects and geometry changes
   - Locate in which layer the defect exists
   - Image damage (C-scan) (Characterize extent.)
   - Provide permanent record

2a. A/C Wheels
   - Crack detection with paint on (The polyurethane coating is being removed solely to facilitate penetrant inspections. Eddy current is specific to bead seat. A similar situation exists for baked resin coating for low-temperature engine components and for coated landing gears.)
   - Rapid, full coverage
     (The inspection technique must easily adapt to the different size rims that must be inspected.)

2b. Honeycomb Panels
   - Rapid coverage of large areas (e.g., large transports)
   - Image damage (C-scan)
   - Provide more realistic accept/reject criteria
   - Detect face/core corrosion
   - Fluid entrapment (Close-out damage leads to water intrusion.)
   - Adaptable to complex geometry (Infrared was suggested. Currently visual and "coin tap" methods are being used.)

3. Corrosion Around Fasteners
   - Rapid coverage of large areas (Which areas require a second look?)
   - Provide indication of potential corrosion
   - Establish detectability requirements
   - Provide inspection data for interpretation by structural engineers

4. Quantification of Corrosion
   - Depth/area of corrosion
     (i.e., Determine the extent of intergranular corrosion before

you grind component down by "brute force" past minimum acceptable thickness.)
(Should an electrochemical approach be used for early detection of corrosion?)

5. Measurement of Coating Adequacy
   - Remaining coating life (in original condition and after a repair)
   - Adequacy of application
   - Applicable to paints/primers/platings/conversion coatings/ion vapor deposited (IVD) coatings/anodic coatings/etc. (Are the protective barriers broken?)

   (i.e., Capability of current eddy current techniques is ± 0.2 mils to measure cadmium plating thickness on high strength steel components due to magnetic permeability and electrical conductivity variations in plating and substrate. How do you compensate for these variations when the critical plating thickness required may be 0.3 mils? Signal averaging by a microprocessor may be one possible method to reduce such errors.

   Specifications for preservation systems and coatings are not applied as rigidly for replacement parts as they are for initial procurements. Uniform buy standards are needed.)

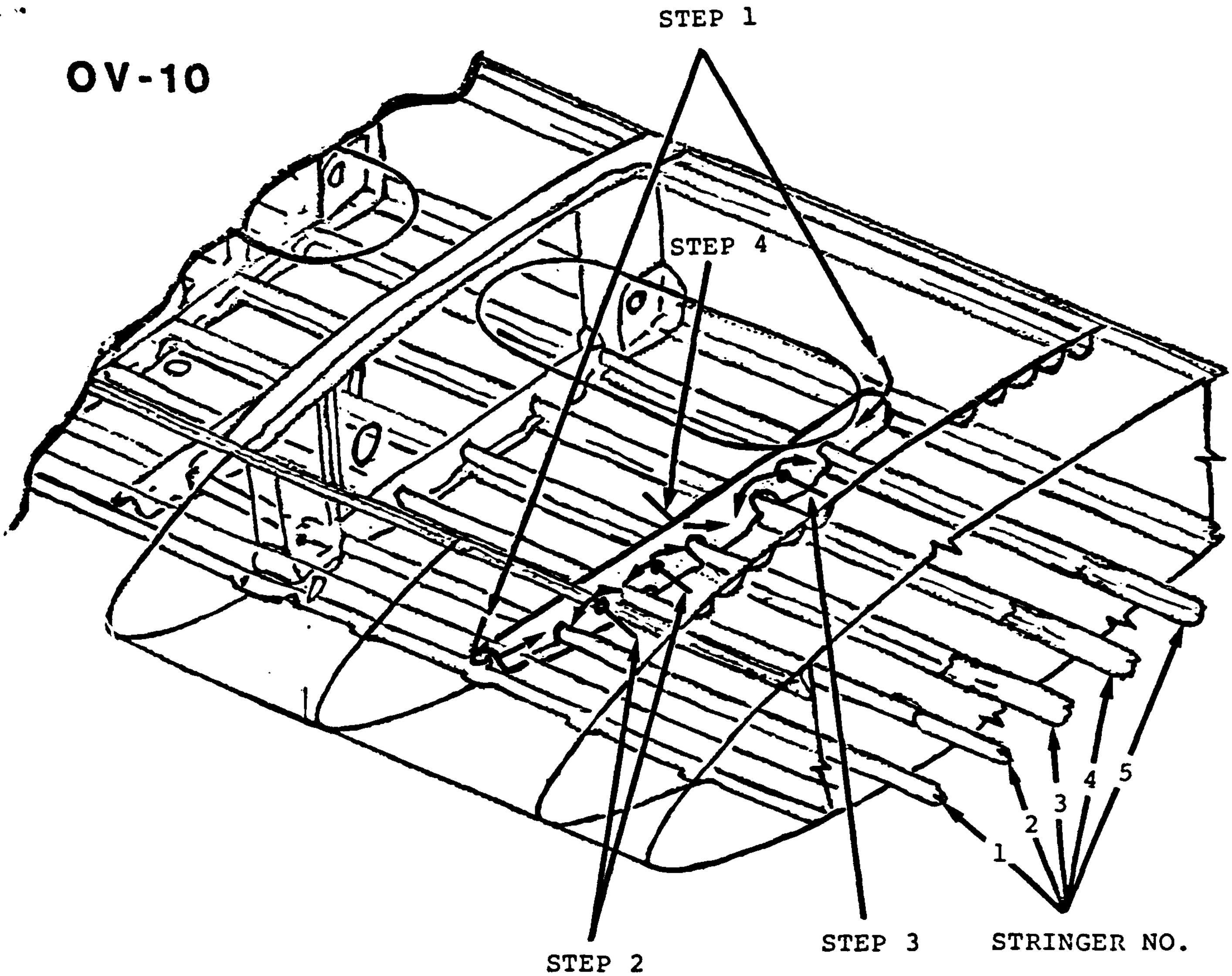
6. Munitions/War Readiness Materiel (WRM)
   - Storage in "sealed" containers
   - Potential application for corrosion probe
     (How does one inspect stored munitions without removal from containers or, minimally, without disassembly?)

7. Corrosion Under Paint
   - Not a problem (Filiform and corrosion under a sound coating system are not problems.)

8. Grinding Damage Under Platings (e.g., chrome plating)
   - More discriminating for base metal damage
     (i.e., Sometimes techniques are too sensitive to grinding patterns without there being any damage in the base metal.)

   (Other considerations arose: There exists a need for standards, qualified inspectors knowledgeable in corrosion and structural mechanics, and sufficient equipment appropriate for the depot or ALC level and for the field level.)

Presented to the concurrent session were two examples of structures which are "accessible" for flexible borescope inspection (Fig. 1 OV-10 Wing Capped Ribs and Stringers) and visual inspection (Fig. 2 T-38 Tunnel Beams and Deck above Tunnel Beams) only upon removal of elastomer fuel bladders and liners. In the case of the T-38A, 120 manhours are required to pull bladders and liners, to inspect, and to replace the fuel cell. Field inspection methods are needed which don't require cell removal. Figures 1. and 2. follow.



Summary of Inspection of OV-10

1. With fuel cell removed, insert flexible borescope in opening at ends of capped rib. Inspect for corrosion inside channel.
2. Use lightening holes (approximately ½ inch in diameter) to insert borescope. Inspect.
3. Through lightening hole between Stringers No. 4 and 5, pass borescope over No. 4 to inspect for corrosion toward No. 3 Stringer.
4. Insert borescope in threaded center hole to complete inspection between No. 3 and 4.
5. Repeat above for each of the capped rib areas on Left and Right wing.

NOTE: The most severe corrosion in capped rib area is exfoliation; inspector looks for swollen metal or for metal shavings from separated exfoliated layers.
NOTE: Talcum powder used to assist in installation of fuel cells and liners may mask exfoliation. Use compressed air to clean such areas and reinspect.

Figure 1. Inspection of Wing Capped Ribs and Stringers Using Borescope

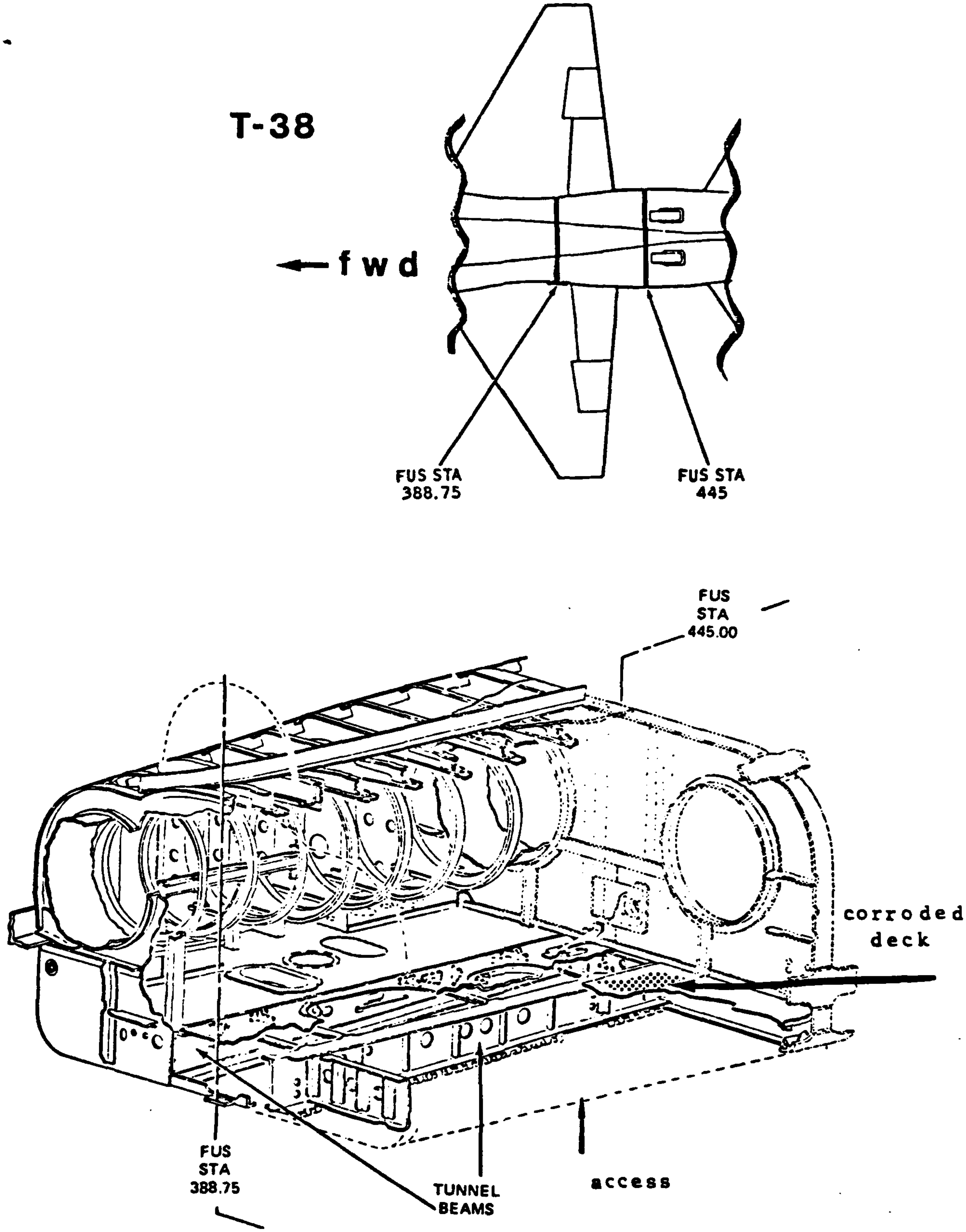


Figure 2. Tunnel Beams/Center Fuselage Section

CONCURRENT SESSION ATTENDANCE LIST

Problem Selection - Accessible Airframe

Chairman: Mr. Grover Hardy

Name	Affiliation
William E. Berner	AFWAL/MLSS (ASD/TAES)
Bernie Boisvert	Universal Technology Corp.
Ronald J. Clay	OO-ALC/MMETP
Mark Forte	AFALD/PTEM
Sarah A. Garrett	General Dynamics/Ft. Worth Div.
Grover Hardy	AFWAL/MLSA
John Hernandez, Lt. Col.	HQ AFSC/SDXP
Ed Holland	NAVAIRSYSCOM
James A. Holloway	AFWAL/MLLP
John Greg Knapik	ASD/AFXM
John Lindsey	HQ MAC/LGMWB
Anthony Martinez	SA-ALC/MMETP
Ira Smart	HQ, US Army, DARCOM/DRCOA-EA
Gary Stevenson	AFWAL/MLSA
Bill Sturrock	DND/DREP, Canada
John Toelaer	TSARCOM, St. Louis MO

CONCURRENT WORKSHOP SESSION:

Problem Selection - Inaccessible Airframe Corrosion
"Generic Corrosion situations in hidden inaccessible locations for which no satisfactory NDE methods exist"

CHAIRMAN: Lt Col Garth Cooke
ASSISTANT: Mr Fred Meyer

Summary (Lt Col G. Cooke)

Inaccessible Airframe

I. General Requirements: (NDI Equipment)

A. At Field Level

Size/weight	-	45 lbs.
Power	-	8-hour battery
Simple	-	Automated
Fast	-	High scan rate

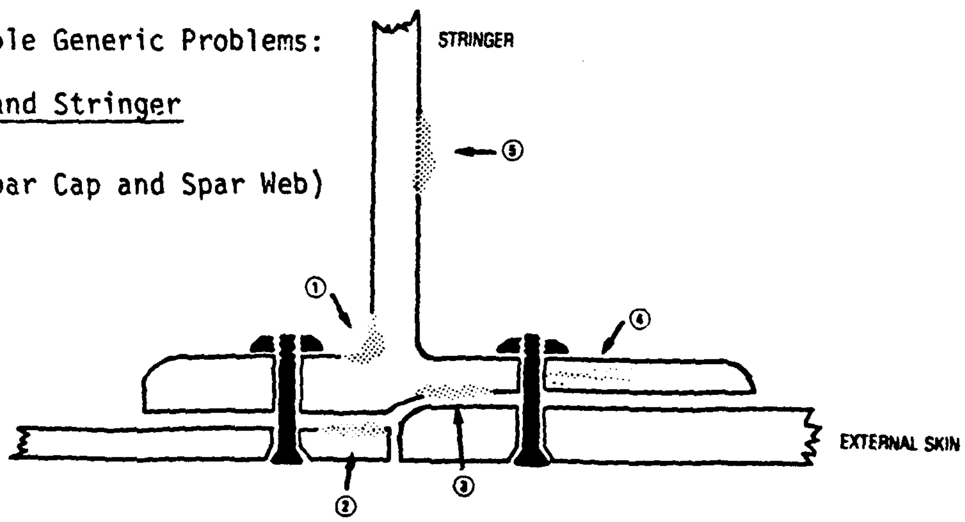
B. At Depot Level

Size/weight	-	45 lbs., portable
		Not applicable/fixed
Power	-	Not applicable/fixed
More complexity allowed		
High scan rate/large area		

II. Inaccessible Generic Problems:

A. Skin and Stringer

(or Spar Cap and Spar Web)



IDENTIFY

(ANY OR ALL OF THESE SURFACES MAY BE COATED BY PAINT SYSTEM AND/OR BY SEALANT)

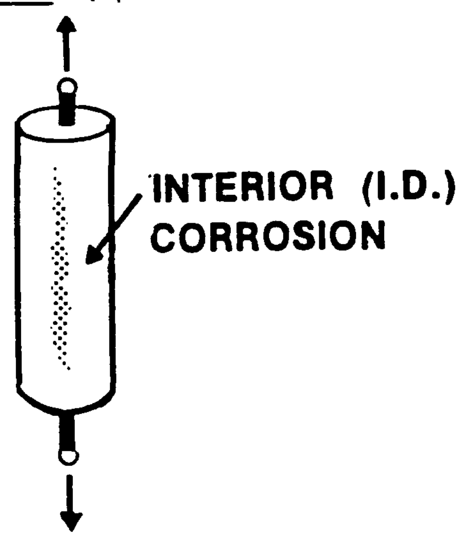
1. CORROSION AT FILLET
2. CORROSION ON UNDERSIDE OF SKIN
3. CORROSION OF INNER STRINGER AT INTERFACE
4. EXFOLIATION CORROSION AT FASTENER
5. CORROSION OF VERTICAL SECTION OF STRINGER (WHICH MAY OR MAY NOT BE UNDERNEATH A SECOND VERTICAL COMPONENT)

For Example:

1. Severe corrosion damage is occurring to the under floor (bilge) area: Corrosive fluids penetrate floor panels and are incompletely drained from the bilge. Similarly, some aircraft with rubber bladder-type fuel cells and fiberglass or nylon/polyester liners require purging, disconnection of fuel lines, removal of bladders and liners to visually inspect primed, anodized Al alloy internal structure/floor which may be coated with sealant or void filler foam. The process of pulling the cell may take 70 manhours and may damage the cell itself.

2. Major corrosion damage occurs in multi-layered window frame structure. Water intrusion through sealant voids initiates corrosion of hidden internal structure which remains undetected until an advanced stage when frames bulge or window delaminates.

B. <u>Hollow Tubes</u> (open or closed at the ends)



(e.g. control rods on helicopters, landing gear trunions; fuel probes with multiple telescoping tubes

C. <u>Honeycomb</u> (For wet or dry corrosion and for delamination)

(More sensitive and consistant, reliable inspection techniques are required to detect the early stages of wet corrosion.)

D. <u>Circuit Boards</u> (Often with conformal coatings)

(Incorrect soldering techniques may cause corrosion under conformal coatings. Improved manufacturing techniques, NDI of IC corrosion, and nondestructive removal of coatings are needed.)

III. New Technology Opportunities:

A. <u>For Skin and Stringer Situation</u> (Without disassembly)

1. X-ray Radiography

Double Wall - Sensitivity of 2-4% of total stackup
Tomography - Impractical for in situ
Tangential - If curved surfaces
Difficult to interpret
Real-Time or Digital Radiography - near real-time
- massage data

2. Neutron Radiography

Requires experienced interpreters
Sensitive to all hydrogen components
(including fuel and sealants)
Detects corrosion products
Radioactive hazards
Greater portability/smaller head

3. Installed "Imbedded" Probes

Ultrasonic array { Microprocessor technology / Signature analysis }
Single probe
Known corrosion prone areas

4. Fiber Optics/Endoscopes

Continued miniaturization
Eyepiece or video screen
Parallel or self-contained light source
Scraper (to examine corrosion products)
Sensory capability (exact location of probe,
what structure am I looking at?)

B. <u>For Hollow Tube Situation</u> (Without disassembly)

1. Horseshoe Shaped Probe
With transducer array

2. Fiber Optics

3. Neutron Radiography (N-ray)

4. Gamma Ray (γ-ray) Irradiation

C. <u>For Honeycomb</u>

1. X-Ray

2. N-Ray

3. Harmonic Bond Tester

4. Ultrasonic Inspection on Bond Line

5. Infra-Red Reflectivity with Chopped Laser

6. Electro-graphic Photography
(Selected planar components with conductive core)

7. Ultrasonic Bubbler System

8. Acoustic Emission

(Current procedures scan a limited area of inspection and are time consuming.)

D. For Circuit Boards (Without removing conformal coating)

1. Built-in Detection - Similar to probe concept (The most corrosion susceptible component by design would signal its own deterioration.)

2. Signal Harmonics
Semi-conductor properties of corrosion products

3. Thermography

IV. Characterization of the Corrosion - The first priority is detection - but once it is found, how bad is it?

Assessment Characteristics which We Need to Know:

	Priority Ranking
A. Extent of Corrosion	(10) (highest)
B. Severity of Attack	(10)
C. Is the Site Actively Corroding?	(9)
D. Rate of Attack	(8)
E. Type of Corrosion	(3) (lowest)

A. Extent of Corrosion (10) (highest)

How much surface area of which component is attacked? What are the x-y-axes changes?

B. Severity of Attack (10)

1. How much sound metal is remaining? What are the z-axis changes or changes in the cross-section of the member?
2. Replacement versus repair - if a critical amount of material is removed during repair, replacement may be necessary anyway.

C. Is the Site Actively Corroding? (9)

1. For areas never before repaired.
2. For previously repaired areas: Is this a sound repair that is still sound? Or, is this a repaired area in which corrosion has been reactivated? (Should different colored paint be used to identify interior repairs?)

D. Rate of Attack (8)

How fast is the corrosion process proceeding? (Critically?)

E. Type of Corrosion (3) (lowest)

(i.e., Concentration cell, galvanic, intergranular, uniform attack, etc.) Need to know type to optimize repair, to design unique repair, if need be, and to treat susceptible area to decrease reoccurrence.

V. Needs Further Discussion:

Use peculiarities of corrosion process to define potential detection techniques (most current techniques use physical properties of metal rather than electro-chemical aspects of corrosion.) (How can one take advantage of corrosion mechanisms that have taken place or are currently taking place at the corrosion site to help find the corrosion and then answer the questions raised in IV?)

CORROSION DETECTION ASSESSMENT

Structure Type	Suggested Technique	Corrosion Assessment Characteristics: Δ (X-Y) Extent	Δ (Z) Severity	Actively Corroding	Rate of Attack	Type of Corrosion	Portable	Ease of Use	Availability: 1-2 Years	3-5 Years	>5 Years
A. Skin & Stringer	Double-wall x-ray	G	A	N/A	N/A	P	G	A	current x-ray	digital x-ray	
	Neutron radiography	G	A	G	N/A	P	P	A to P		✓	
	Probe	P to G	P to G	G	G	N/A	N/A	G	P	A	
	Fiber optics	G	N/A	P	N/A	P	G	G	✓		
B. Hollow Tubes	Horseshoe shaped probe	G	P	N/A	N/A	N/A	G	G	✓		
	Fiber optics	G	N/A	P	N/A	P	G	G	✓		
	Neutron radiography (N-ray)			(See above under Part A.)							
	Gamma attenuation	G	G	N/A	N/A	N/A	G	G to A	✓		
C. Honeycomb	X-ray, N-ray			(See above under Part A.)							
	Harmonic Bond Tester	P to G	N/A	N/A	N/A	N/A	G	G	current		
	Ultrasonic NDI on Bond Line	P to G	N/A	N/A	N/A	N/A	G	G			
	IR Reflectivity w. chopped Laser	G	A to P	?	?	A	G	A		✓	
	Electrographic Photography			(Limited application)					✓		
	Ultrasonic Bubbler		(Limited application to bond integrity)						current		
	Acoustic emission	P	P	A	A to P	N/A	A	A			
D. Circuit Boards	Imbedded probe	P to G	P to G	N/A	G	N/A	N/A	G	✓		
	Signal harmonics		(Limited application)						?		
	Thermography		(Used for QA in manufacturing)						✓		

G = good, A = average, P = poor, N/A = not applicable

CONCURRENT SESSION ATTENDANCE LIST

Problem Selection - Inaccessible Airframe Corrosion

Chairman: Lt Col Garth Cooke

Name	Affiliation
Windel Baker	AVRADCOM, NDI
Jerry Carr	Corpus Christi Army Depot
Maurice Carter	AFWAL/MLSA
Richard Chance	Grumman Aerospace
Bennie Cohen	AFWAL/MLSA
Garth R. Cooke, Lt Col	HQ AFLC
Bob Dahl	SM-ALC, McClellan AFB CA
Pat Daniels	Sikorsky Aircraft
Danny R. Daugherty, MSgt	Corrosion Mgr. TAC/LGMD
Lee Gulley	AFWAL Manufacturing Technology
Ed Holland	NAVAIRSYSCOM
M. Khobaib	AFWAL/MLLN
Henry W. Kleindienst	Fairchild Republic Co., F'dale NY
Terry Mattson	Boeing Co.
Fred Meyer	AFWAL/MLSA, WPAFB OH
Nancy M. Norton	AFWAL/MLLP, WPAFB OH
Peter Opar	USAir
R. C. Placious	National Bureau Standards
Dan Sheets	AFCOLR/ES, WPAFB OH
Bill Sproat	Lockheed-Georgia
Mike Stellabotte	NADC
Jesse R. Teal, Jr., Lt Col	WR-ALC/MMEM, Robins AFB GA
John Toelaer	Blackhawk PM, TSARCOM

CONCURRENT WORKSHOP SESSION:

Inspection/Detection Methodology - General Constraints
"Long term vs. near term (how futuristic?)
Applicability for corrosion detection (how feasible?)
Impact of signal processing/microprocessors."

CHAIRMAN: Mr Joseph Koos
ASSISTANT: Mr Stephen Moore

<u>Summary</u> (Mr J. Koos)

<u>Inspection/Detection Methodology</u>

I. Session Make-Up:

Air Force	Army	Navy	Industry
9	1	1	6

II. Key Technology Deficiencies/Development Needs:

- Set Criteria for Corrosion
    - What is "BAD"?
    - What is the critical size of a pit?
- Develop Standard Methodology for Analysis
- Training
    - Make it realistic
    - Training aids/Handbook development
    - Simulation (long term need)
- Rapid Inspection of Large Areas
- I.D. [inner diameter] Tube Inspection for All Size Tubing
- Composite/Metal Interface Inspection
- Inspection Under Paint/Sealant
- Corrosion Under Fasteners

III. Equipment Dislikes:

- Transient Readout with No Permanent Record
- Lack of a Probe Indicator
- Manual Scanning

- Probe Sizing (e.g. Low Frequency Eddy Current)
- Operator Dependency

IV. Technology Opportunities:

- Ultrasonic Flaw Discriminators
- Computer Aided Tomography
- Real Time Radiography
- Nuclear Magnetic Resonance (Moisture Detection)
- Acoustic Emission Advanced Development
- New Probe Materials (Size Reduction)
- Pulsed Eddy Current
- Microprocessors/Microcomputers
- Ultrasonic and Eddy Current Reference Standards (Method of Fabrication)
- Electro-Chemical Probe Techniques
- Corrosion Probe Interpretation/Electrode Development
- Electric Current Perturbation
- Signature Analysis
- NDE Modeling Techniques (long term need)

V. Proposed Specific Program Objectives/Tasks:
There were seventeen program needs submitted by individual members of this Workshop Session as a starting point for further discussion. These are summarized below, unranked.

A. <u>Corrosion Definition</u>

1. Maximum Allowable/Minimum Detectable Corrosion Limits

Objective: Recognize corrosion as an integral part of Structural/Engine/Avionics Integrity Programs.

Tasks: a. Accomplish the structural testing necessary to establish limits on corrosion damage needed to be detected (similar to present minimum flaw detection requirements).

b. Critically examine current equipment and procedures to establish equipment/process capabilities or limits in detecting corrosion defined by a.

c. Develop new equipment/procedures if needed.

2. Reference Standards

Objective: Establish methods and processes to produce test specimens containing varying types and degrees of corrosion.

Tasks: a. Develop methodology for producing specimens containing varying types of corrosion.
b. Establish methods to control the "growth" of corrosion and to quantify/validate the extent of such "growth" within a specimen.
c. Establish standardized processes/procedures for initiation, "growth", control and validation of various types of corrosion.

B. Development of Specific NDI Techniques

1. Ultrasonic (UT) Flaw Discrimination

Objective: Provide further improvements in this technique to aid in rapid, automatic interpretation of flaws (corrosion).

Tasks: a. Provide faster response than is presently available.
b. Provide signal analysis for improved flaw characterization.

2. UT Discriminators

Objective: Conduct exploratory assessment of UT response to various corrosion types and degrees of severity, i.e. establish the physics of the bulk and the discrete problem.

Tasks: a. Survey the state-of-the-art of potential candidates; spectrum analysis; UT goniometry.
b. Study of signal/noise discrimination by techniques used.
c. Develop prototype, field test, and finalize design.

3. Resonant (Pitch/Catch) Eddy Current (EC) Probes for Detection of Corrosion Under Paint

Objective: Detect accessible surface corrosion.

Tasks: a. Optimize for fast area scan with portable, battery-operated impedance plane (CRT) instruments.
b. Test how useful the instrument developed in a. is for detection of second layer (subsurface corrosion thinning and stress corrosion cracks).

4. EC Technology Development

Objective: Perform exploratory assessment of EC probe design and EC instrument design improvements for detection of corrosion damage.

Tasks: Evaluate the following:
a. Probe size - ferrite development for improved flux density control in small probe sizes;
b. Probe type - e.g. pancake spiral, rotating low frequency, pulse/reflection, and narrow gap (tape recorder);
c. Instrumentation - pulsed, dual pulse (resonance), rotating field presentation and detection, and multiple coil (goniometer type); and
d. Sensitivity (signal/noise ratio response to varying corrosion types and severities).

5. Electric Current Perturbation (ECP)

Objective: *Develop ECP equipment for corrosion detection in* selected components, i.e. Al, Ti.

Tasks: a. Feasibility studies:
(1) Obtain simple configuration specimens with typical corrosion.
(2) Perform experimental data acquisition and parameter investigation.
(3) Conduct data analysis/assessment.
b. Demonstrate typical components using bread-board hardware.
c. Develop prototype hardware for selected components at depot/field.

6. Acoustic Emission Testing (AE)

Objective: Determine the applicability of AE for detecting corrosion other than moisture in honeycomb assemblies.

Tasks: a. Determine suitability of AE for detecting intergranular corrosion, exfoliation, stress corrosion, etc.

Note: Improvement on existing applications to honeycomb *is being pursued by SM-ALC under PRAM*[1] *funding.*

7. CAT (Computer Aided Tomography) Scan

Objective: Establish proof of principle and development of prototype model using robotics technology.

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[1]System or equipment Producibility, Reliability, Availability and Maintainability

Tasks: a. Conduct a laboratory assessment of capabilities and discrimination levels for various types and degrees of corrosion.
b. Develop and demonstrate a prototype system using robotics to transport and position detector module.

8. NMR (Nuclear Magnetic Resonance)

Objective: Develop rapid large area scanning NMR-NDE system for detection of moisture and moisture degradation of composite structures.

Tasks: a. Assess moisture detection capability in typical structural specimens.
(1) Obtain specimens from Air Force.
(2) Determine sensitivity ranges.
(3) Determine repeatability.
(4) Evaluate probe configurations.
(5) Determine inspection speeds.
b. Demonstrate on typical components using bread-board hardware to:
Conceptual design of prototype stage.
c. Develop of prototype hardware for use at Depot/field to:
Delivery and training stage.

9. Corrosion Probe

Objective: Expand testing of corrosion probes.

Tasks: a. Improve design of probes to obtain better reliability and expanded use.
b. Expand tests for aircraft/areas/conditions.
c. Correlate data to define the extent of success of of this program and probable usage throughout the aircraft industry.

10. Electrochemical Techniques

Objective: Develop further automated electrochemical techniques employing scanning microprobes and impedance measurements for detecting corrosion susceptible areas on metals and metal/coating systems.

Tasks: a. Demonstrate feasibility on a variety of different metal/coating systems and on a variety of different geometries, including weldments.
b. Develop better microprobes and scale-up for scanning larger surface areas.
[Note: Previous work includes Hugh Isaacs, Brookhaven National Laboratory; and Florian Mansfield, Rockwell Science Center. Another area of interest is hydrogen embrittlement.

The Navy (NADC) has developed the so-called "Barnacle Electrode", which uses an electrochemical technique to determine the susceptibility of a component.]

11. Specific Electrode Development

Objective: Conduct exploratory development to assess capabilities for applying specific ion electrodes and area electrodes for detection of the onset of corrosion and the progression of corrosion.

Tasks:
a. Survey the state-of-the-art to select potential application of specific ion or other specific electrochemical sensors to corrosion onset and progression in aluminum, steel, and titanium.
b. Perform laboratory demonstration of selected electrodes to establish signal response to varying types and degrees of corrosion.
c. Demonstrate in the laboratory the "area" electrode approaches to detect and quantify degree of corrosion.

C. Signal Processing/Data Processing

Objective: Fulfill a need for microprocessor/microcomputer based data processing.

Tasks:
a. Extract additional information from a given signal, such as frequency, amplitude, spectral information.
b. Provide comparison information between the test signal and a standard, the preceding signal.
c. Have a system which presents the total picture of any given scan-generated inspection, e.g. generalize systems such as the In Service Inspection System (ISIS).

D. Training/Inspection Aids

1. T.O. -33B Handbook on Corrosion Detection

Objective: Solicit to have a handbook prepared like the adhesive bonding handbook.

Tasks: This handbook should describe the following:
a. Mechanisms of corrosion
b. Type of corrosion
c. NDI methods for detection and measuring the extent of the damage
d. Corroded area repair techniques
e. Corrosion prevention methods useful for aircraft maintenance.

2. Training Aids - Flaw Simulator

Objective: Establish a computer-based ultrasonic trainer incorporating elements of classical classroom training and a skills-development ultrasonic simulator.

Tasks:
- a. Establish methods for producing a real-time dynamic, ultrasonic (UT) simulator to visualize the path of sound and varying reflection modes within an object as a transducer is moved.
- b. Couple the real-time CRT response of signals from transducer/test object/flaw dynamic interactions to both a monitoring CRT (instructor's) and the display/simulator of the individual whose proficiency is being upgraded (analogous to a language laboratory situation). Alternately, utilize the modular trainer in the teaching-machine mode, one-on-one.
- c. Incorporate a real-time capability to exercise operator skills with varying signal/background noise levels. Unit would serve as the NDT proficiency development unit.

3. Flaw Simulation

Objective: Provide training of inspectors on methods used to detect/evaluate corrosion with emphasis on simulation of realistic flaws.

Tasks:
- a. Provide typical corrosion flaw simulation, particularly in EC and UT, for training purposes.
- b. Provide extensive training of inspectors on all aspects of corrosion detection/evaluation.

CONCURRENT SESSION ATTENDANCE LIST

Inspection/Detection Methodology - General Constraints

Chairman: Mr Joseph Koos

Name	Affiliation
Robert Andrews	University of Dayton Research Institute
R. W. Bailey	WR-ALC NDI Prog. Mgr., Robins AFB GA
Bob Barton	Southwest Research Institute
Phillip C. Borja	Naval Air Rework Facility (North Island)
Roger Griswold	AFWAL/MLSA
Donald Hagemaier	McDonnell Douglas (Long Beach)
MSgt. David W. Hubbard	ASD/AEGS Subsys/Support Equip. SPO
Joe Koos	AFALD/PTEM
Fred Latta	ASD/ENFSS
Jim Lawyer	HQ AFLC/MAXT, WPAFB OH
Milt Levy	AMMRC, DRXMR/MMS, Watertown MA
A. Lopez	SA-ALC/MMEI, Kelly AFB TX
John Moore	Rockwell International, B-1 Div. L.A. CA
Steve Moore	SM-ALC/MAQCA, McClellan AFB CA
Jim Pittman	Fairchild Republic
Ward D. Rummel	Martin Marietta
Emory Stewart	USAF/AFLC, WPAFB OH

SUMMARY

Characteristic of a subject as complex as the NDE of Corrosion, the recommendation of the several Working Groups contained many facets, the details of which varied according to the inspection situation under consideration. During the Plenary Session at the conclusion of the Workshop an effort was made to identify some common properties of NDE techniques that would be desirable regardless of the specific inspection situation.

The Plenary Session discussion resulted in a natural separation of the common properties desired into two classes, those for techniques that inspect for corrosion under paint and those for techniques that inspect for corrosion in built-up structure, so-called "hidden" corrosion. These results are given below.

Corrosion Under Paint	"Hidden" Corrosion[1]
• Large Area Scan Capability (X-Y extent)	• Limited Area, Critical Location Scan (Determined by structural analysis and field maintenance experience)
• Automated Inspection	• Semi-Automated with "Permanent" Inspection Record
• Field-Usable	• Field-Usable (Ease of set-up) (Reproducible) (Multi-task capability) (Rugged equipment)
• Use of Indirect Measure of Corrosion - Paint Property (Coating integrity?) - Paint Formulation (Such that paint reacts with corrosion products to signal non-exterior corroded areas)	• Use of Corrosion Products to Detect Corrosion
	• Quantification of Corrosion Damage (How severe?) (Accept/reject criteria?)
	• Ability to Use Technique on Variety of Geometries

[1] Evaluate without disassembly

Two other issues that generated considerable discussion during the Plenary Session of the Workshop were:

(1) The need for improved corrosion detection training for inspectors, and

(2) The need for greater awareness, on the part of aircraft designers, of the problems of corrosion in structures and in the difficulties of detecting corrosion in fully assembled, in-service aircraft.